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# **EXTRAVEHICULAR CREWMAN WORK SYSTEM (ECWS) STUDY PROGRAM**

## **FINAL REPORT VOLUME 4 PROGRAM EVOLUTION**

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**EXTRAVEHICULAR CREWMAN WORK SYSTEM  
(ECWS)  
STUDY PROGRAM  
CONTRACT NAS 9-15290**

**FINAL REPORT  
VOLUME 4  
PROGRAM EVOLUTION**

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July 1980

**HAMILTON STANDARD**  Division of  
UNITED TECHNOLOGIES

## **FOREWORD**

**The Extravehicular Crewman Work System is a study of manned extravehicular activity centering about construction and satellite servicing in Earth orbit.**

**This report is divided into four volumes:**

<b>Volume 1</b>	<b>Executive Summary</b>
<b>Volume 2</b>	<b>Construction</b>
<b>Volume 3</b>	<b>Satellite Service</b>
<b>Volume 4</b>	<b>Program Evolution</b>

**This volume, Volume 4, Program Evolution, provides an overview of the work performed in the study.**

**This study program has been performed under contract by Hamilton Standard for the National Aeronautics and Space Administration, Lyndon B. Johnson Space Center over a period from April 1977 to June 1980.**

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# EXTRAVEHICULAR CREWMAN WORK SYSTEM STUDY PROGRAM

## Final Report, Volume 4, Program Evolution

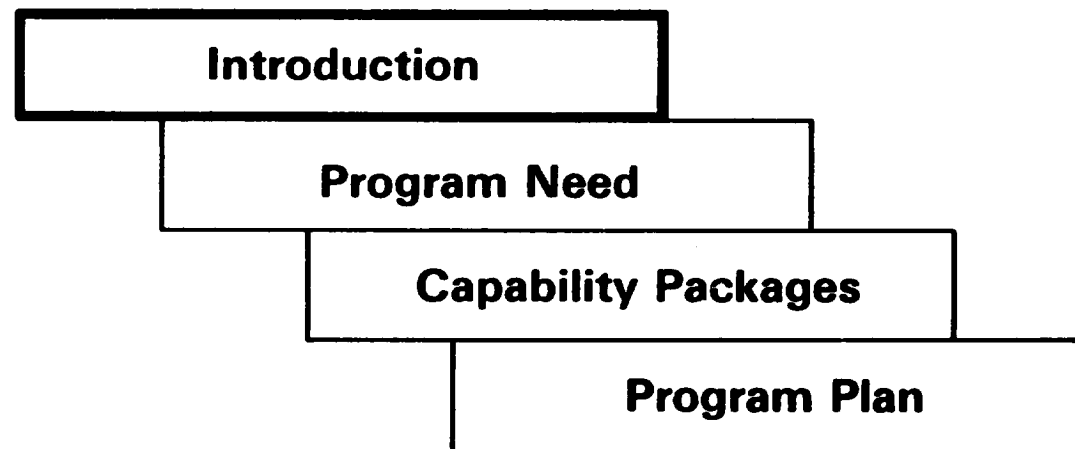
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# **EXTRAVEHICULAR CREWMAN WORK SYSTEM STUDY PROGRAM**

## **Final Report, Volume 4, Program Evolution**



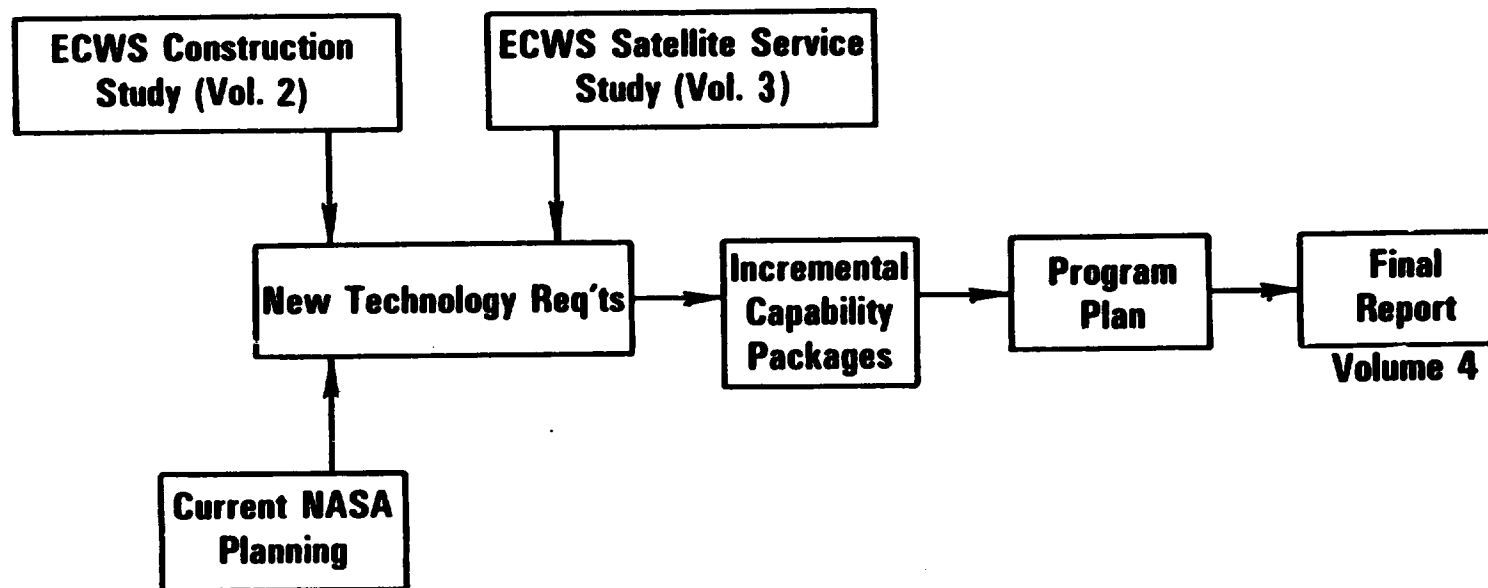
## INTRODUCTION

The objective of the program evaluation portion of the Extravehicular Crewman Work System (ECWS) study program is to define the new technology requirements for equipment to support space construction and satellite service in-orbit. The following conclusions were drawn from this study.

- EVA capability can follow a logical evolution that meets the requirements of both satellite servicing and the changes in the STS.
- The evolution can be broken down into a series of incremental capability steps.
- The resulting ECWS is capable of supporting both satellite service and space construction.



## ECWS PROGRAM EVOLUTION STUDY FLOW

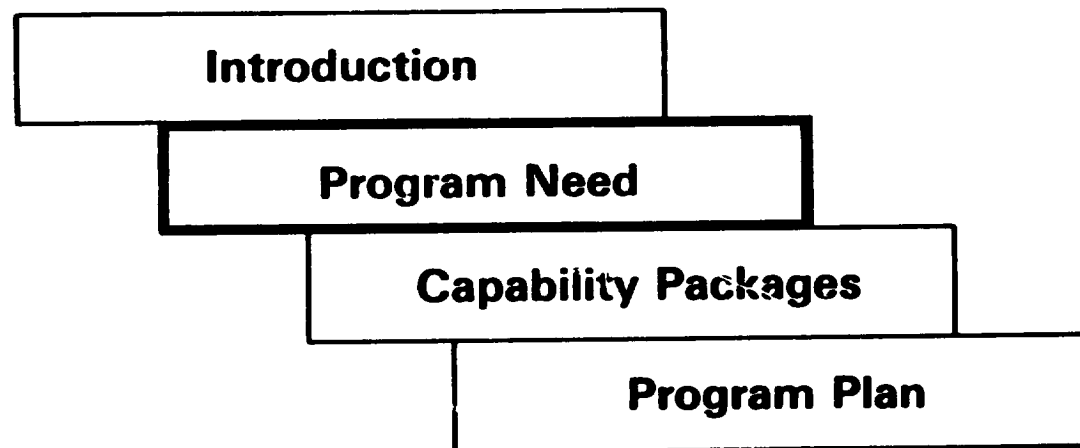


### ECWS PROGRAM EVOLUTION REPORT

The ECWS Program Evolution Report covers the following topics

- STS need for increased EVA capability.
- Incremental EVA capability packages, including new technology items.
- Program plan defining the schedule of required new technology development.

**EXTRAVEHICULAR CREWMAN WORK SYSTEM  
STUDY PROGRAM**  
**Final Report, Volume 4, Program Evolution**



## PROGRAM NEED

EVA was used to achieve major mission objectives of the Gemini, Apollo and Skylab programs. EVA is a baseline capability in the present STS program. Space Station System Analysis Studies indicate that EVA will be required to support future construction activities in orbit. This section discusses in broad terms the near future need for EVA to support satellite servicing and space construction. A plan is presented for evolving EVA capability in step with developing capability of STS. This discussion is structured as follows:

- . STS evolution plans
- . Satellite population characteristics
- . Space platform concepts and characteristics
- . STS Mission and vehicle trends
- . EVA capability evolution

## 10 YEAR NASA OSTS PLAN

The following nine pages are excerpted from the NASA OSTS Plan for FY 1981 (draft) to define current NASA broad-scale planning.

### 1990's Environment

Projected features of the 1990's environment which will have significant impact on the space program are:

- Increasing Third World pressures will create market for space technology and services.
- Energy scarcity and social program pressure will put increasing pressure on funds.
- Continuing international tensions will increase need for space technology.

### Implications for Space Program

- Moderate evolutionary development of space capability, not an Apollo "crash program"
- Advanced technology use and multi-function capability to take advantage of common elements and economies of scale.
- Increasing satellite complexity will mean increased failure probabilities, driving the need for on-orbit maintenance capability, both by remote control and by manned, in-situ operation.
- Continuously manned facilities will be required for repair and refueling of satellites, as well as for large structure construction.

### Goals & Objectives

Sensitivity of goals and objectives to changes in the environment should be able to affect the rate of accomplishment.

- Long range goal of 1980's - Establish permanent occupancy in LEO.
- Long range goal of 1990's - Establish a manned GEO facility.

Objectives to support the long range goals are:

- Develop for routine operation during the mid 1980's the Shuttle, Spacelab, IUS, SSUS and ground facilities.

10 Year NASA OSTS Plan (Continued)

- Develop large, unmanned, high power, multi-function, Shuttle-tended free flyers in LEO for routine operation by the mid 1980's.
- Develop a permanent, manned facility for routine LEO operation by the end of the 1980's.
- Develop and operate a permanent, remotely serviced, non-tended and laker-manned facility in GEO by the late 1990's.
- Achieve a major reduction in space transportation costs.

The evolution of the capability to support these objectives is shown in the accompanying illustration.

# EVOLUTION OF SPACE TRANSPORTATION SYSTEMS NEEDS

	<b>[Goal:] Permanent/Manned Occupancy of Low Earth Orbit</b>		<b>[Goal:] Operate Manned Geo-Synchronous Facility</b>
	<b>1980-1985</b> <b>Objective: Routine Operation of Shuttle/Spacelab, IUS, SSUS, MMU</b>	<b>1985-1990</b> <b>Objective: Permanent/Manned Facility in Low Earth Orbit</b>	<b>1990-2000</b> <b>Objective: Manned Geo-Synchronous Facility</b>
<b>Transportation</b>	<ul style="list-style-type: none"> <li>• Bring present STS to operational status</li> <li>• Develop high-energy stage (SEPS)</li> <li>• Augment thrust to improve Shuttle performance</li> </ul>	<ul style="list-style-type: none"> <li>• Develop Interim Cargo OTV (IOTV)</li> <li>• Improve Orbiter habitability for extended staytime</li> </ul>	<ul style="list-style-type: none"> <li>• Develop Cargo OTV</li> <li>• Develop Crew Capsule</li> <li>• Develop Shuttle-derived HLLV</li> </ul>
<b>Services</b>	<ul style="list-style-type: none"> <li>• Orbiter health determination</li> <li>• Satellite services near Orbiter (placement, retrieval, module replacement)</li> </ul>	<ul style="list-style-type: none"> <li>• Adapters, tools, devices for operations using Orbiter RMS</li> <li>• Maintenance &amp; repair of satellites in sight or Orbiter</li> <li>• Satellite services remote from Orbiter (placement, retrieval, module replacement)</li> </ul>	<ul style="list-style-type: none"> <li>• Service systems for routine operations remote from Orbiter and in geosynchronous orbit</li> </ul>
<b>Platforms</b>	<ul style="list-style-type: none"> <li>• Power Extension Package (PEP) for Shuttle</li> <li>• Large structures experiments definition</li> <li>• Develop free-flying power modules, experiment platforms, and materials processing modules (unmanned/STS-tended)</li> </ul>	<ul style="list-style-type: none"> <li>• LEO manned facility with service modules, habitation modules, flight support modules, and construction modules</li> <li>• Large structures experiments and demonstrations</li> </ul>	<ul style="list-style-type: none"> <li>• Develop large power module</li> <li>• Develop GEO facility (manned)</li> </ul>

## Transportation

The evolution of advanced space transportation is illustrated in the accompanying illustration. The plan is divided into low-orbit lift vehicles, and vehicles for orbit transfer above low-earth-orbit.

The Shuttle is in development and is expected to become operational in 1981. By 1984, the Shuttle's low-Earth orbit performance will have to be augmented for Air Force missions from VAFB that will require placing a 32,000-lb payload into a 98° polar orbit.

Preliminary studies have shown how much the Shuttle's performance can potentially be increased with strap-on, solid rocket boosters or by replacing the Shuttle's present Solid Rocket Booster with a liquid rocket booster (LRB). NASA is continuing to study those forms of augmentation in anticipation of their need in the early 1990's in connection with large space systems. The LRB block change has the potential of increasing the Shuttle's payload delivery capability from 65,000 pounds to 100,000 pounds, with no increase (possibly decrease) in cost per flight, with essentially no change in the Orbiter.

The lower half of the illustration shows the planned evolution of the transportation capabilities for missions requiring high energy propulsion. The ability of the STS to provide easy access to space will increase operational flexibility and decrease the cost of space transportation. In its early years, the STS will be the sole means for deploying, fabricating, and servicing payloads and structures in space. However, the STS will require augmentation for the higher velocity planetary missions planned for the mid and late 1980's, and for deploying and servicing the geosynchronous platforms and large space systems planned for the late 1980's and early 1990's. NASA plans to satisfy those requirements with various combinations of the Solar Electric Propulsion System (SEPS) the IUS, and, later, orbital transfer vehicles (OTV's) and the Shuttle-derived heavy lift launch vehicle (HLLV).

## Satellite Service

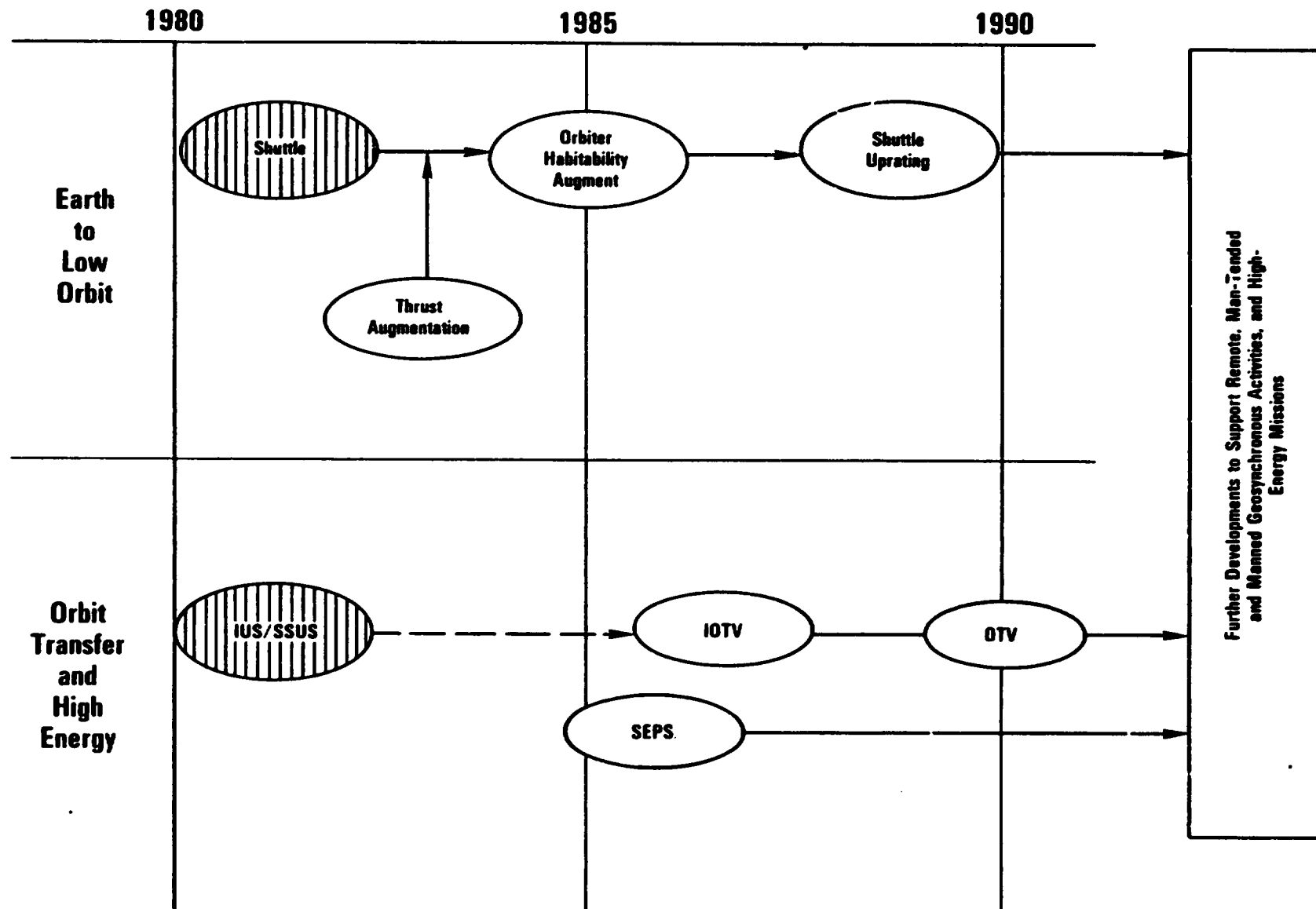
The objectives of the Satellite Service program are to define, develop, and demonstrate capabilities for placement, retrieval, and in-orbit maintenance and repair of satellites, and for retrieval of unstable satellites and space debris. Provision of those services in locations remote from the Shuttle imposes requirements that are considerably different from the requirements related to the provision of services near the Shuttle.

## Services Near to Shuttle

The initial capability for satellite placement and limited retrieval will be provided by the Shuttle-mounted Remote Manipulator System (RMS), the integrated space suit and backpack, and the Manned Maneuvering Unit. However, space systems such as the Long Duration Exposure Facility, Multi-Mission Spacecraft, Space Telescope, and low-Earth-orbit science and applications platforms will require improved and new services, as well as equipment to provide those services.



# EVOLUTION OF ADVANCED TRANSPORTATION CAPABILITIES



Needed equipment will include such things as maintenance and repair equipment, berthing platforms, end effectors (mechanical hands) for the RMS, support equipment for Shuttle crew members to use in extra-vehicular activity (EVA) servicing operations, a remote work station called the "Cherry Picker" mounted to the free end of the RMS arm and television support systems. NASA plans to develop and demonstrate those items of equipment in the 1984-1985 period for subsequent operational use.

### Services Remote from Shuttle

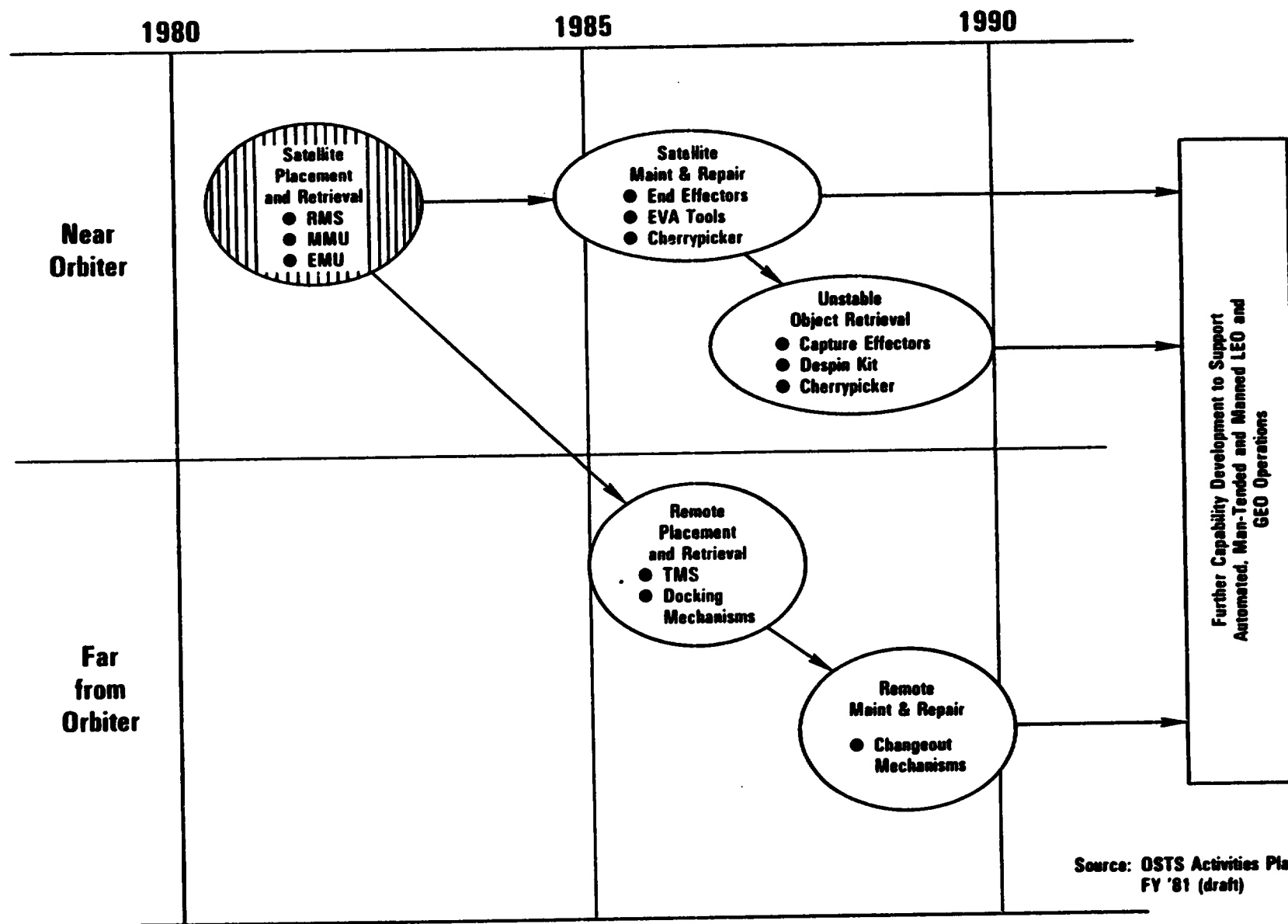
Teleoperator Maneuvering System (TMS) will be a remote control system benefiting considerably from the technology developed for the recently terminated Teleoperator Retrieval System that NASA had planned to use to boost Skylab to a higher orbit. It will be able to provide significant services to satellites remote from the Shuttle. Two potential modes of operation are being considered: An Orbiter-controlled operational mode for object retrieval or servicing up to the limits of line-of-sight ( $\sim 2000$  miles), and a ground-controlled mode which would have unlimited range. By the mid-1980's NASA could demonstrate the TMS's ability to retrieve objects 800 to 1,600 kilometers from the Shuttle. Then, equipped with a front end having a mechanism for changing spacecraft modules, it could demonstrate a capability to remotely perform satellite maintenance and repair. Its ability to retrieve remote, unstable objects (satellites or debris) will require front end kits to despin, grapple, and capture those objects. NASA should achieve that ability about 1986 or 1987. Demonstration of the ability of a teleoperator service module teamed with an OTV to service a satellite in geosynchronous orbit will be possible in the late 1980's.

### Space Platforms

The Shuttle is a platform with a nominal stay time in space of 7 days, too short a time for maximum benefit to some experiments. The initial improvement in platform capability will be to equip the Shuttle with the Power Extension Package, which will increase that stay-time to 12 to 20 days depending upon orbit inclination. With the advent of the 25KW Power System, the on-orbit stay of the Orbiter can increase the maximum capability of the Orbiter in conjunction with significant increases in electrical power and thermal control, and provide a contamination-free environment through the Power System attitude control. With the Power System/Orbiter capability in the Sortie mode as a basis, the natural evolution is for yet longer orbit stay-times for payloads. The Power System in a free flyer mode will provide for a direct transition of Sortie pallets and payloads to the Power System with minimal modification and integration. With instruments and/or pallet-mounted payloads being attached directly to the Power System, the free-flying platform system is capable of indefinite periods of operations with minimum Shuttle-tending.

In order to achieve the capability for research, construction, and space operations in the most economical manner practical, and to expand capabilities beyond the earlier stage of free-flying Shuttle-tended platforms, NASA will provide for manned operations in LEO with reduced dependence on Earth for control and resupply. Using the 25KW Power System, a habitation and various operations modules which could be outgrowths of preceding developments, the permanent/manned LEO facility will evolve in the later 1980's to be fully operational by the end of the decade.

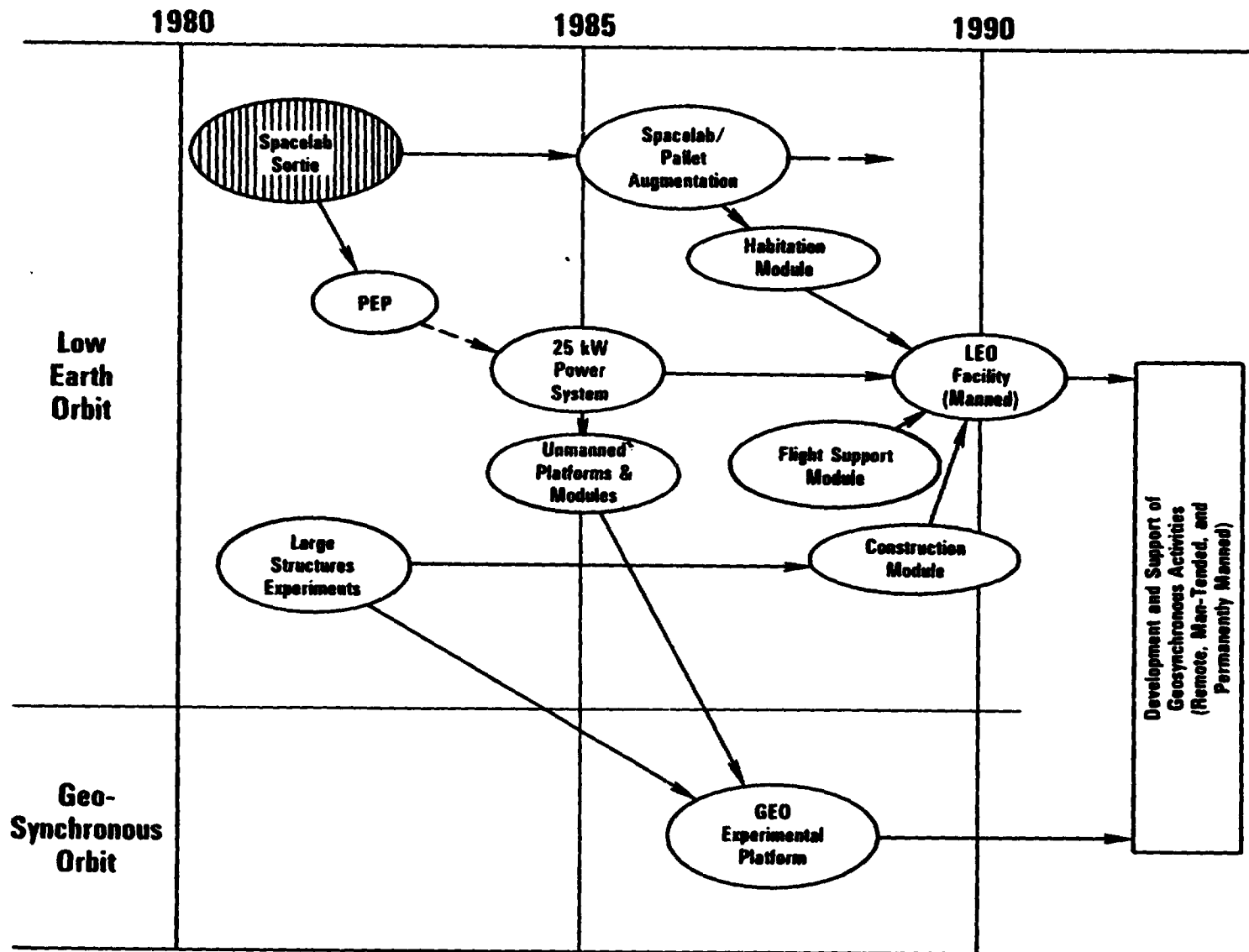
# EVOLUTION OF SATELLITE SERVICES CAPABILITY



Some experiments in materials processing, physics and astronomy, and the life sciences will have unique requirements for services or will require a pressurized environment. NASA will satisfy those requirements by developing special modules. Later, when a number of those science and applications programs can benefit from a geosynchronous orbit location, NASA will develop suitable geosynchronous platforms, making all possible use of the technology and experience we have derived from development, construction, and operation of low-Earth-orbit platforms.

The larger structures for use in both low-Earth-orbit and geosynchronous orbit will have to be assembled or fabricated in space. Some of them may be fabricated there by means of the beam fabricating machinery and other hardware to be developed in a Large space Structures System Engineering program.

# EVOLUTION OF SPACE PLATFORM CAPABILITIES

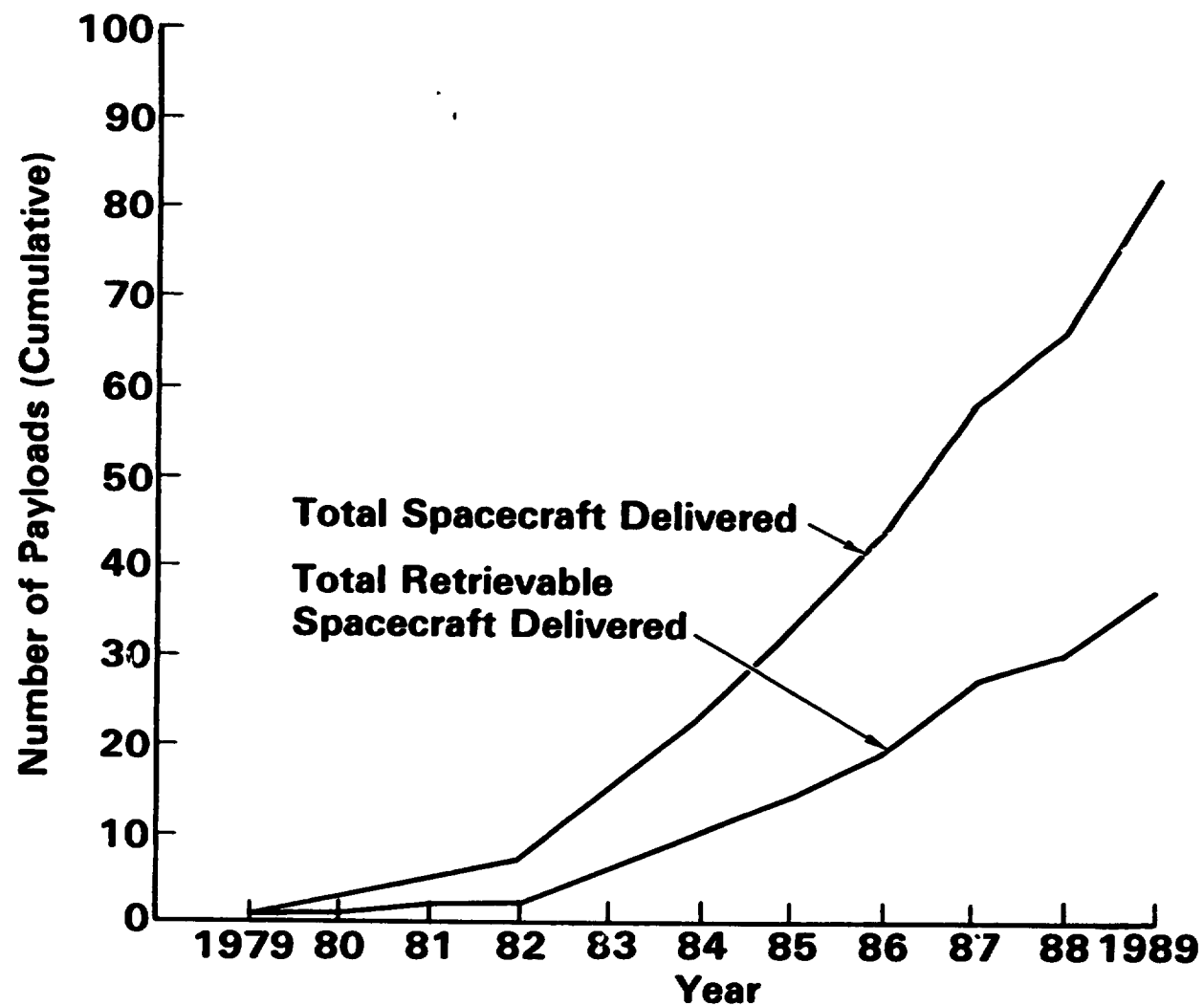


### SATELLITE LAUNCH AND SERVICE

STS Traffic models and payload manifests are moving targets, as shown by the accompanying projections, both dating from 1979. However, the common denominators are:

- Frequent STS flights are planned once the Shuttle becomes operational.
- The satellite population will grow rapidly throughout the 1980's.
- Satellites designed for on-orbit service will represent a significant fraction of the total satellite population.

## SATELLITE POPULATION PROJECTION — LEO (4)



## SERVICES MISSION MODEL (3)

Automated Payloads	80	81	82	83	84	85	86	87	88	89	90	91	Total
<b>Launches</b>													
• Physics & Astronomy			1	3	3	6	5	7	5	6	5	8	95
• Lunar & Planetary			2		1	1	2	1	2		2	1	12
• Applications		2	1	3	6	6	4	3	2	3	3	1	34
• Space Technology	1		1		2	1	1	1	1	1	1	1	11
• NASA Related	2	3	1	2	2	2	5	4	6	5	6	6	44
<b>Total</b>	<b>3</b>	<b>5</b>	<b>6</b>	<b>8</b>	<b>14</b>	<b>16</b>	<b>17</b>	<b>16</b>	<b>16</b>	<b>15</b>	<b>17</b>	<b>17</b>	<b>150</b>
<b>Serviceable Satellites</b>													
• Physics & Astronomy				1	2	2	2	4	2	4	2	4	23
• Lunar & Planetary													0
• Applications		1	1	2	2	3	4	1	1	1	3		19
• Space Technology	1		1		2		1	2	2	2	2	2	15
• NASA Related		1	1	1	1	1	2	2	2	2	2	2	17
<b>Total Serviceable</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>7</b>	<b>6</b>	<b>9</b>	<b>9</b>	<b>7</b>	<b>9</b>	<b>9</b>	<b>8</b>	<b>74</b>
<b>% Service</b>	<b>33</b>	<b>40</b>	<b>50</b>	<b>50</b>	<b>50</b>	<b>38</b>	<b>53</b>	<b>56</b>	<b>44</b>	<b>60</b>	<b>53</b>	<b>56</b>	<b>49</b>

\*Some in LEO



# SATELLITE CHARACTERISTICS

## Representative Satellites

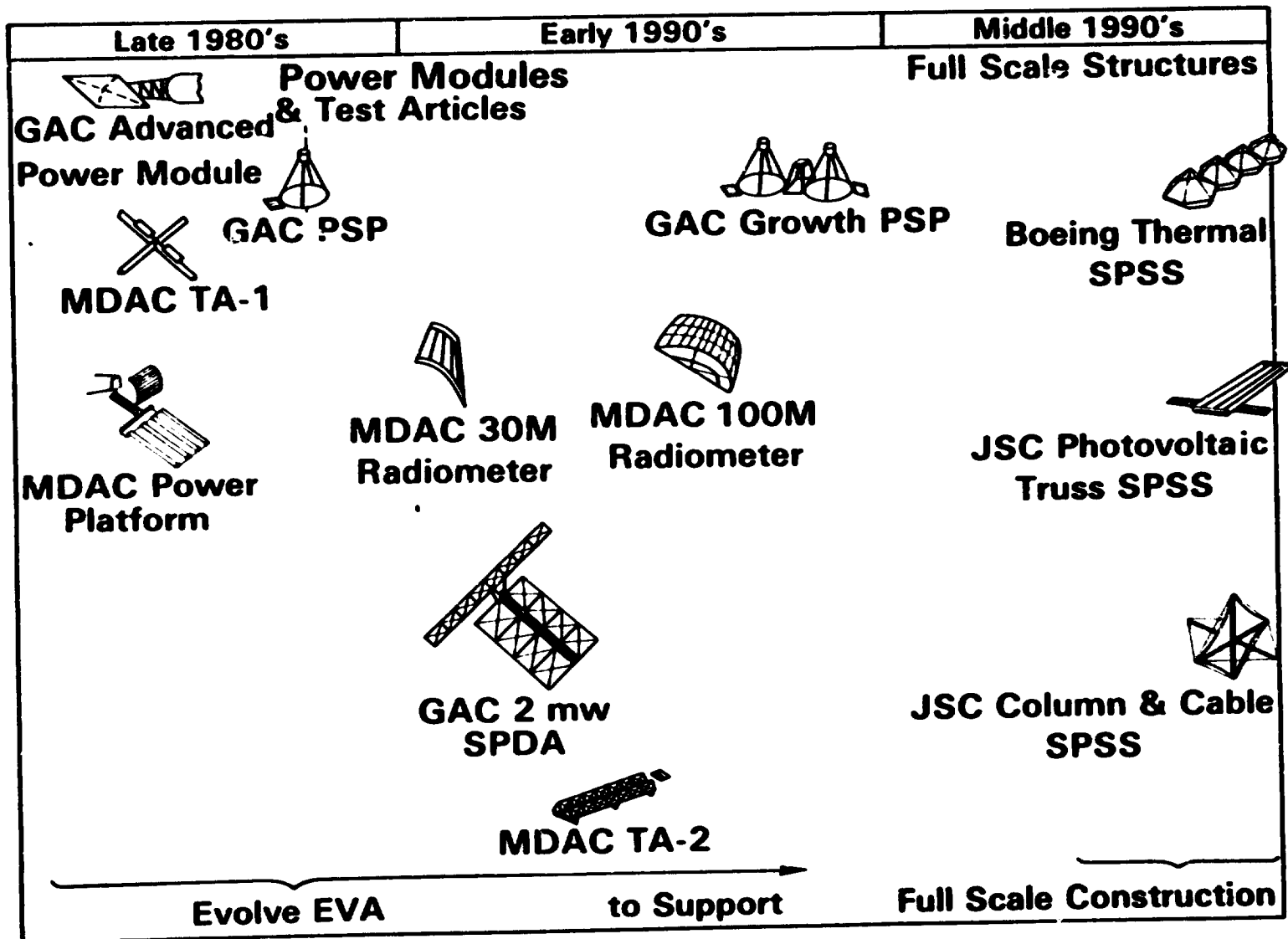
The following tabulation highlights characteristics of several satellites launched during the 1970's or projected for launch during the early 1980's.

Satellite	Launch	Orbit	Geometry	Length	Diameter	Weight	Payload	Mission
	Year	N. Mi.		Ft	Ft	Lb		
Landsat	1972-77	560	Cylinder	10	4	2,000	Photography	Earth Resources Study
HEAO	1974	340	Octagonal Cylinder	19	9	10,000	X-Ray & Gamma Ray Sensors	High Energy Astronomy
Seasat	1978	430	Cylinder	35	6	4,000	Active & Passive Radar, IR	Ocean Study & Weather
LDEF	Early 1980's	300	12 Sided Cylindrical Frame	30	14	User-Dependent	Experiment Trays	Exposure to Space Environment
Space Telescope	Mid 1980's	270	Cylinder	42	15	21,000	Optical Telescope	Visible Light Astronomy
25 kW Power System	Mid 1980's	200-250	Box	34	10	28,000	Solar Panels	Power for Extended Orbiter Missions
MMS	Mid-Late 1980's	270-864	Triangular Box	5+ Payload	6	10,000+	User-Dependent	Multi-Mission Modular Concept

### SPACE PLATFORMS

Later use of STS capability is projected for construction of space platforms of different types. The following illustrations show representative space platform structures and structural elements, as discussed in recent Space Station System Analysis Studies.

# REPRESENTATIVE TEST ARTICLES AND FULL SCALE STRUCTURES



## SUMMARY OF MAJOR EARLY CONSTRUCTION ELEMENTS

<u>Element</u>	<u>Weight</u>	<u>Dimensions</u>
Brace Cabling	1300 kg	2 m Dia. x 1 m
Rotary Joint	165 kg	1m x 1m x 1m
Electronics Pkgs	75 kg	0.5m x 0.5m x 0.5m
Complete Assemblies	7800 kg	30 x 250 m
ACS Pods	60 kg	1m x 1m x 1m
Composites Fabrication Module	4660 kg	4.4m Dia. x 15m
Construction Jig's	8700 kg	40 x 110 x 7 m
IUS Stages	30,000 kg	2m Dia. x 20m Long
Cargo Pallets	15,000-30,000 kg	5-20 m
Worksite Platform	150 kg	1 x 3 x 2 m

#### MANNED MISSIONS AND VEHICLE TRENDS

The foregoing identified major STS capability objectives, components and projected time schedules, as well as project characteristics of the satellite population and space platforms. This background information is consistent with the accompanying projection of manned mission and vehicle trends, which, in turn, shapes the evolution of EVA capability.

# MANNED MISSION AND VEHICLE TRENDS

Evolutionary Phase	7 Day Shuttle	Extended Duration Orbiter	Habitation Module	Space Platform	Large Structure Construction
Characteristics					
Time Frame	1980's, 90's & Beyond	Middle 1980's	Late 1980's	Early 1990's & Beyond	Middle 1990's & Beyond
Mission			<u>Tended</u> <u>Permanently Manned</u>		
• Duration	0 to 7 Days	7 to 60 Days	30-60 Days 40-180 Days	-	-
• Crew Size	4-7 People	4-7 People	4-7 People 3-10 People	5-30 People	100 People Habitat, 3 Habitats/SPS
• Orbit	28% LEO 55 LEO 98 LEO -	28% LEO 55 LEO 98 LEO TBD -	28% LEO 55 LEO 98 LEO TBD GEO TBD	28% LEO 55 LEO 98 LEO TBD GEO TBD	28% LEO - - GEO
• Activity	Scientific Research Mfg Process Demo 25 kW Power System Payload Development, Servicing & Retrieval Resupply All Permanently Manned Missions	Scientific Research Mfg Process (Small Scale) 25 kW Power System Deliver Large PM (250 KW) Perform Structure Feasibility Testing	Scientific Research Mfg Process (Commercial Scale) Build & Use Large PM Build & Test Initial SPS/PSP Demo & Test Articles, & Const Facility	Scientific Research Mfg Process/Commercial Scale Build & Test Service Advanced SPS/PSP Demo & Test Articles	Build, Checkout, Activate, & Service Full Scale SPS/PSP's
• EVA					
No. EVA Crew	2 People	TBD	2-4 People	TBD	300 People/SPS
Sortie Frequency	4 Nom, 6 Max/Crewman/Flight	Up to 6 Days/Week	6 Days/Week	6 Days/Week	6 Days/Week
Sortie Duration	Up to 7 Hours	6-8 Hours	6-8 Hours	6-8 Hours	4-8 Hours
• Prebreathe	Required	Not Req'd	Not Req'd	Not Req'd	Not Req'd
ECWS Design Drivers					
• Radiation	28% LEO - No Problem - 55 LEO - Duration Too 98 LEO - Short	28% LEO - No Problem 55 LEO - Potential Problem for 98 LEO - Repeated EVA's	28% LEO - No Problem 55 LEO - Problem for Habitat & ECWS 98 LEO - Potential Problem for Habitat/ECWS  GEO - Problem for Habitat & ECWS	28% LEO - No Problem 55 LEO - Problem for Habitat & ECWS 98 LEO - Potential Problem for Habitat/ECWS  GEO - Problem for Habitat & ECWS	28% LEO - No Problem - - GEO - Problem for Habitat & ECWS
• Consummables Management			<u>Tended</u> <u>Permanently Manned</u>		
Power	Fuel Cells	Solar, Augmented by Fuel Cell	Solar	Solar	Solar
H <sub>2</sub> O	Fuel Cells	Stored, Augmented by Fuel Cell	Stored, Recycled	Stored, Recycled, Saved	Stored, Recycled, Saved
O <sub>2</sub>	900 psia Cryo	900 psia Cryo	900 psi Cryo	Electrolysis	Electrolysis
CO <sub>2</sub> Removal			WVE or TBD		
CO <sub>2</sub> Reduction	LiOH Expendable Dump	HSC Regenerable Dump	HSC Regenerable Dump	HDC	HDC
• EVA Tasks	Payload Deployment/Retrieval Payload Maintenance/Servicing Small Structure Deployment	Payload Deployment/Retrieval Payload Maintenance/Servicing Fabrication & Assembly Demo.	Test Article Construction, Oper. and Servicing and Maintenance	Test Article Construction, Oper. Servicing and Maintenance	Full Scale Structure Construction Operation, Servicing, and Maintenance
• EVA Transit Distance	100' w/Communications Umbilical 100m w/MMU	100m w/MMU	100m w/MMU	Up to 10 km	Up to 10 km for SPS

### EVA EVOLUTION TO SUPPORT STS CAPABILITY

This discussion summarizes the macroscopic features of EVA evolution to support the developing STS capability.

- Primary STS uses are:
  - Spacelab for performing experiments
  - Launch, retrieval & service of satellite
  - Base for man-tended operations
- EVA is cost effective for
  - Satellite servicing
  - Debris retrieval
  - Space Platform construction
- Developing STS use drives increased EVA capability:
  - More convenient use
  - Longer EVA Sorties
  - Reduced dependence on STS Consumables

# EVA EVOLUTION TO SUPPORT STS CAPABILITY

## EVA Tasks

### ● Construction

- GEO
- Full Scale Structures
- Development & Test Articles

### — Stabilization

- — — — — Satellite and Debris Retrieval

### — Diagnosis

### — Structural Repair

### — Debris Stowage

### — Trim & Safe

### — Refuel

### — — — — — Module Replacement

### — — — — — Inspect

### — Berth

### — Deploy

### ● Satellite Service

### ● Baseline

### — Payload Support

### — Contingency

Time →

### ● Capability

Payload  
Launch Sorties

Experiments  
Satellite Serv.

Communi-  
cations  
Const. Dev.  
Mat'l Proc.

Construction

### ● Vehicle

Shuttle/  
Spacelab

Shuttle/  
Spacelab  
+ PS

Shuttle-  
Tended Habi-  
tat + PS

Construction  
Base + Habitat

PS ≡ 25 kW Power System

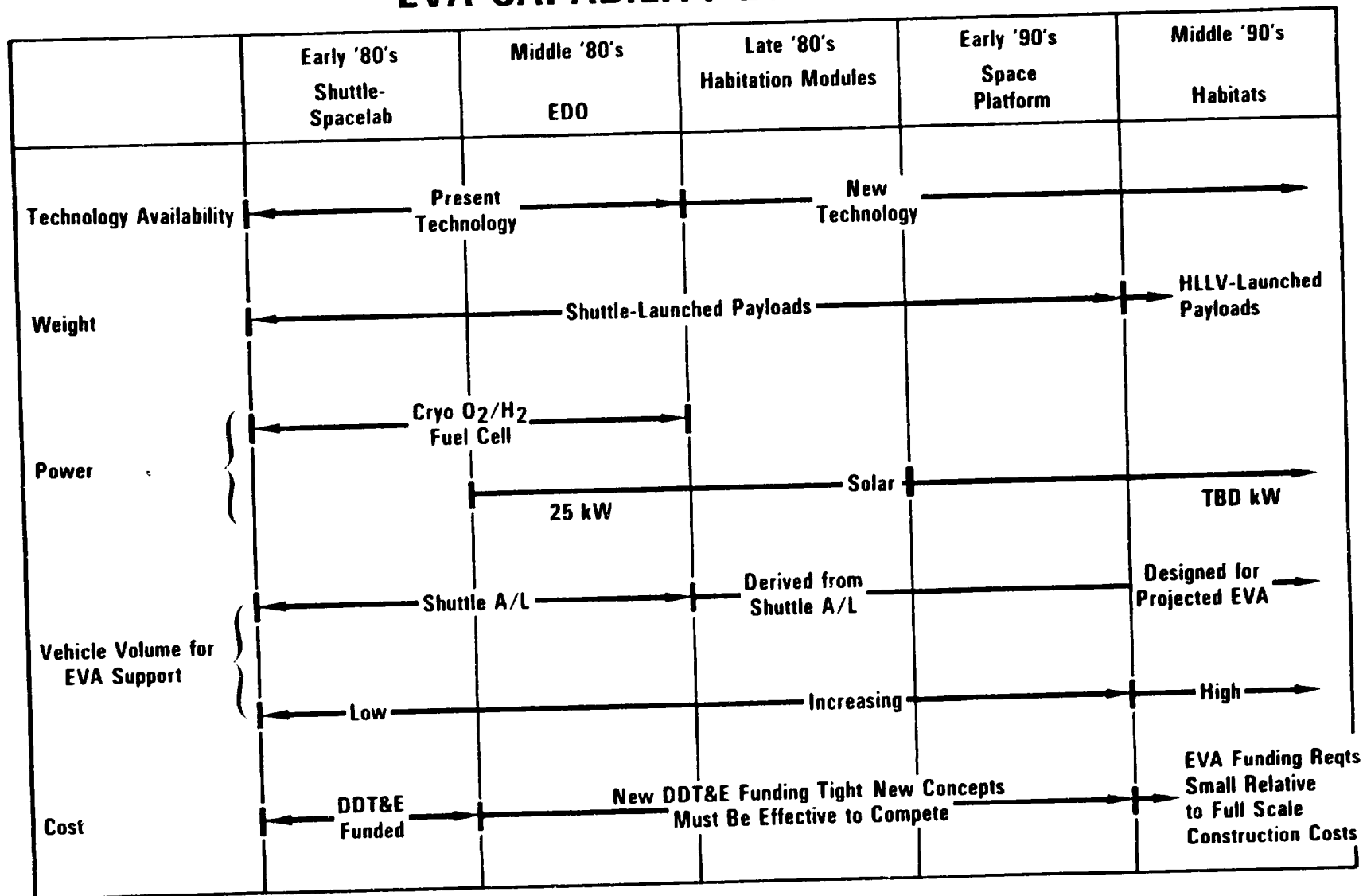


## MANNED MISSION AND VEHICLE TRENDS AFFECT EVA CAPABILITY EVOLUTION

The STS is an evolving capability with projected steps defined with some degree of certainty, but with flexible scheduling. Hence, EVA evolution concepts must retain general applicability, but not become tied to any one program time frame. However, the following macroscopic trends of the STS program are incapable, and it is to these that EVA evolution must be carefully attuned:

- EVA evolution is a long term concept. Technology availability constrains new concept selection up to the middle 1980's. However, for the later 1980's and beyond, time exists to develop new technologies, which opens up the range of EVA evolution concepts for consideration.
- For satellite service and construction missions EVA resupply requirements will compete with structure payload for the Shuttle's volume and weight lifting capability. Large scale construction, on the other hand, is expected to use an HLLV concept to launch structure payloads. EVA resupply considerations will be a much smaller fraction of such payloads, and therefore, EVA equivalent weight and volume significance will become somewhat reduced.
- The transition from fuel-cell power to solar power will reduce the availability of fuel-cell byproduct water for EVA cooling. Hence EVA cooling will have to move away from total dependence on expendable water.
- The present Shuttle devotes just a 150 ft<sup>3</sup> airlock and a small mid-deck area with stowage lockers to EVA provisions. This limits EVA equipment volume to that of the present EMU out through the EDO phase. Habitation modules conceived in the SSSAS reports employ the Shuttle airlock. The modules are accompanied by an expanded adjacent volume which could be used to store and service EVA equipment somewhat larger than the EMU. However, EVA equipment must be able to pass through the 1 m dia international docking hatch. Further in the future, construction habitats would be configured to support EVA as their primary purpose, and thus their volume allotments would be driven by EVA support considerations. Structure too, will become more spacious, minimizing the requirements for access to small or narrow spaces. Thus, the long term trend is for EVA equipment volume to decline somewhat in significance.
- Until a national commitment to large scale space construction is made, EVA DDT&E money will be tight. Concept candidates will be carefully screened for cost effectiveness. However, once a large scale construction program commitment has been made, it is expected that EVA costs will become a small fraction of the total program. Thus, EVA costs will be expected to decline somewhat in significance.

# MANNED MISSION AND VEHICLE TRENDS AFFECT EVA CAPABILITY EVOLUTION



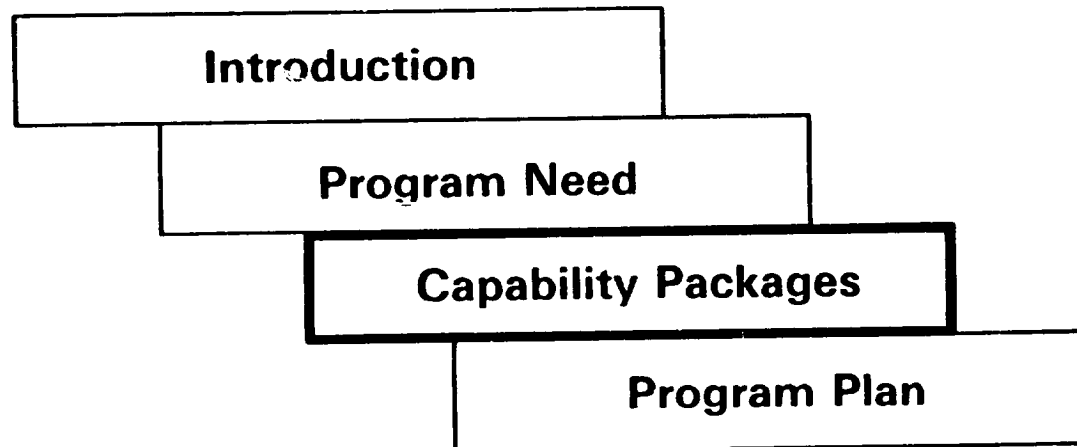
DDT&E = Design, Development,  
Test and Evaluation

#### Manned Mission and Vehicle Trends Affect EVA Capability Evolution (Continued)

- EVA will increase as the satellite population and scope of construction projects increase. Accordingly, the orientation of the payload specialist will change from that of the scientist/ engineer to that of the technician or construction worker who uses EVA capability to perform useful work in space. Thus the EVA will become more like a tool, in which utility and dependability become increasingly important.

# **EXTRAVEHICULAR CREWMAN WORK SYSTEM STUDY PROGRAM**

## **Final Report, Volume 4, Program Evolution**



## SEQUENTIAL EVOLUTION OF EVA CAPABILITY

It is recommended to evolve baseline EVA capability, which consists of the present EVA and MMU, in a series of steps that track the planned STS development. These steps are called capability packages, whose broad features are as follows:

### Baseline

- Use the baseline EMU and MMU to perform payload support tasks, such as experiment boom deployment, film retrieval and payload contingency tasks.
- Support satellite operations by assisting with deployment and berthing, as well as performing inspection and module replacement tasks.

### Satellite Service

- Improve EVA convenience and capability by reducing or eliminating prebreathe requirements and by providing a wide angle vision, automatic visor helmet and rugged, high tactility gloves.
- Evolve a mature satellite service capability using a three step tool and equipment development program.
  - Work restraint to provide two-handed work capability, adapters and hand tools to facilitate module replacement, fluid handling facility to support satellite fluid consumables replenishment, and debris stowage for returning replaced items to Earth.
  - Power hand tools to perform structural repairs and to reduce the inventory of individual hand tools.
  - Fluid isolation, leak detection and diagnostic equipment to permit satellite subsystem diagnosis, repair and checkout.

### Improved EMU

Improve EMU effectiveness to support increasing EVA levels owing to the rising population of serviceable satellites and to accommodate the projected change in vehicle power source.

- Phase in rugged, long life space suit assembly (SSA) elements, such as replaceable SSA soft goods and workplace hazards protection tailorable to expected radiation levels at various orbits.

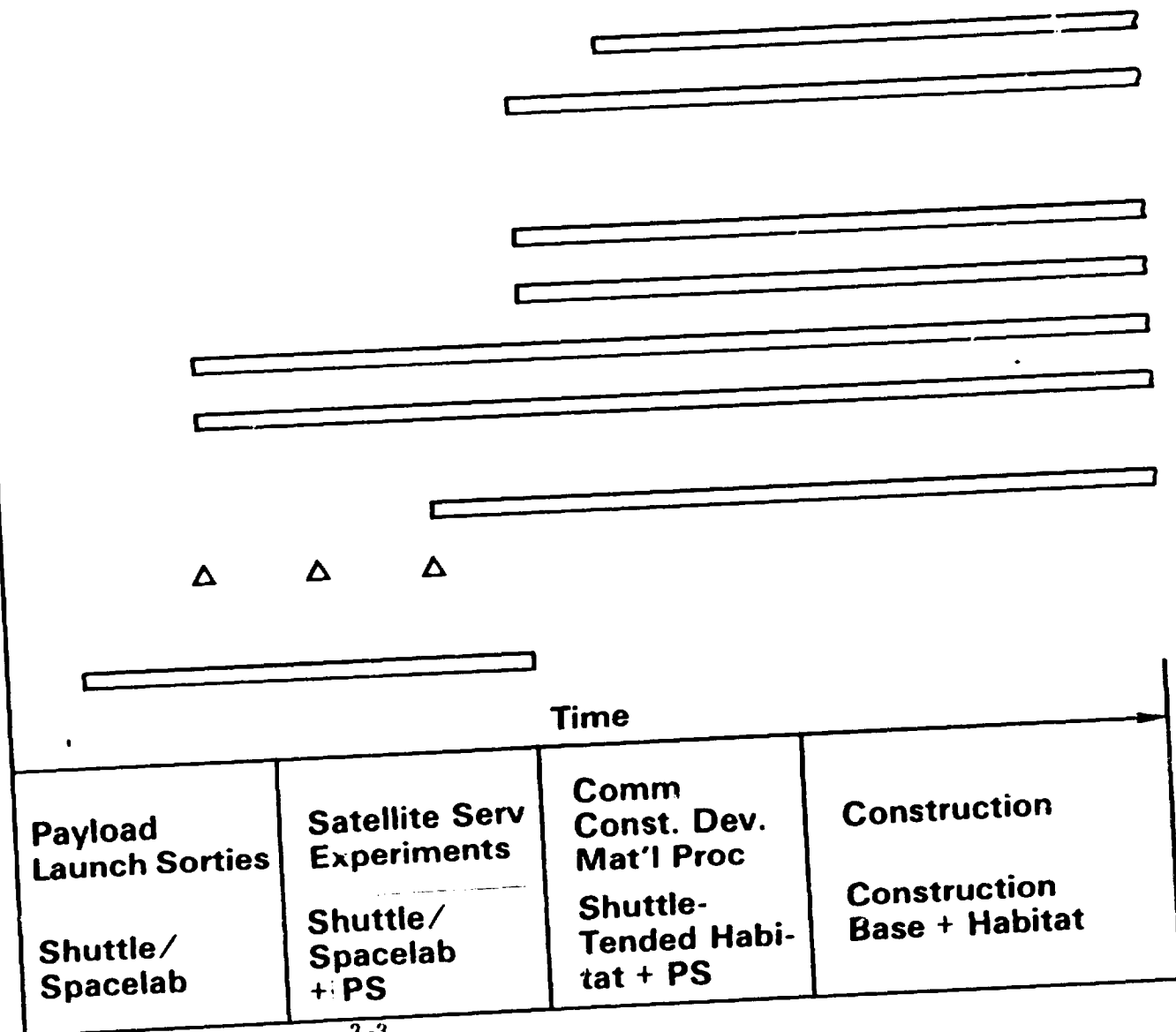
# EMU EVOLUTION TO SUPPORT STS CAPABILITY

## EVA Capability

- Remote Operations  
EVA Stabilization  
Construction, Service & Improved Retrieval
- Improved EMU  
Long Life SSA  
Non Expendable LSS  
Improved Helmet & Gloves  
Computer, No Prebreathe
- Satellite Service  
Tools & Equipment  
3-Steps
- Baseline  
EMU, MMU

## STS Evolution

- Capability
- Evolution



### Sequential Evolution of EVA Capability (Continued)

- Reduce EMU Life Support System (LSS) consumables use by implementing a regenerable CO<sub>2</sub> removal subsystem and a non-expendable heat sink. Repackage the LSS to accommodate the new subsystems and to permit various LSS configurations to support a variety of EVA tasks and durations.
- Increase the existing caution and warning system computer capability to support future EVA in locations more distant from the Orbiter.

### More Distant Operations

Support increasingly ambitious satellite service and construction requirements by developing an EVA capability for more distant locations.

- Develop a high V MMU to support an EVA free-flying range of approximately 10 km from the orbiter.
- Develop a rigid leg enclosure with an optional manipulator module to perform task requiring a strong grip or long reach.
- Develop equipment for direct EVA stabilization and retrieval of out-of-control satellites and large debris.

Specific capability packages are defined in the accompanying illustration. Rationale for the capability package sequence is as follows:

- Seven increments will develop EVA capability from present baseline to operations up to 10 km distant.
- Increment sequence is consistent with STS capability evolution.
- Increments track increasing satellite population and serviceability.
- Increments group interrelated changes together to simplify program management.
- Increments reflect technology development leadtimes.
- Increments develop EVA capability first in vicinity of Orbiter. This allows accumulation of experience and confidence before committing to more distant EVA.

# SATELLITE SERVICE CAPABILITY PACKAGES

Pkg	Increasing Service Capability	Capability Package Required		
7.	More Distant EVA Capability <ul style="list-style-type: none"> <li>- EVA Stabilization &amp; Retrieval</li> <li>- Free Flying Debris Collection</li> <li>- Construction</li> </ul>			Pkg 5+ Stabilization Kit Retrieval Kit Debris Kit Use of Enhanced Computer Capability
6.	Near-in EVA Capability <ul style="list-style-type: none"> <li>- Snoring Assistance</li> <li>- Remote Diagnostics &amp; Service</li> <li>- Construction</li> </ul>		Pkg 5+ Satellite Service MMU TV Monitor Remote Service Kit Manipulator Module Rigid Leg Enclosure	
5.	Improved EMU Capability <ul style="list-style-type: none"> <li>- Reduced Consumables Use</li> <li>- Support High EVA Levels</li> </ul> Increased Satellite Service Capability	Pkg 4+ Long Life SSA & Incremental Hazards Protection Regenerable CO <sub>2</sub> Removal Non-Venting Heat Sink 8-Hr EVA Capability Enhanced Computer Capability Repackaged LSS		
4.	• Mature Service Capability <ul style="list-style-type: none"> <li>- Fluid System &amp; Minor Electrical Repairs</li> <li>- Electrical/Electronic Diagnosis &amp; Checkout</li> </ul>	Pkg 3+ Subsystems Diagnostics & Checkout Kit Leak Detection Kit Fluid System Refill Kit Fluid Isolation Kit		
3.	• Structural Repair <ul style="list-style-type: none"> <li>- Material Cutting &amp; Bonding</li> <li>- Rapid Fastener Handling</li> </ul>	Pkg 2+ Hand-Held Power Tool Fuse-Bond Tool		
2.	• Routine Servicing <ul style="list-style-type: none"> <li>- Subsystem Safetying &amp; Debris Stowage</li> <li>- Lens/Sensor Cleaning &amp; Refueling</li> <li>- Two-Handed Work Capability</li> <li>- Eliminate Probreaths</li> </ul>	Pkg 1+ Service Materials, Supplies, & Repair Parts Hand Tools, Tool Caddy & Tram Line Baffles, Shields & Adapters Work Platform & Adhesive Bond Gun Wide Angle Helmet & Rugged Gloves Decontamination		
1.	Baseline Capability <ul style="list-style-type: none"> <li>- Normal &amp; Contingency Deployment &amp; Berthing</li> <li>- Inspection of Orbiter &amp; Payloads</li> <li>- Module Replacement</li> <li>- Tide Repair, P/L Door Closure, Rescue</li> </ul>	Shuttle EMU RMMU RMS Select Hand Tools		

Payload Bay & RMS Envelope

Within 100m

Within 10 km

Work Distance from Orbiter or Habitat



## CAPABILITY PACKAGE NO. 1

### 1. Capability

Baseline capability using existing Shuttle EVA equipment.

### 2. Equipment

EMU, MMU, RMS, Select Hand Tools & Supplies

### 3. Satellite Operation

Deployment, berthing, inspection

### 4. Satellite Subsystems

Entire satellite.

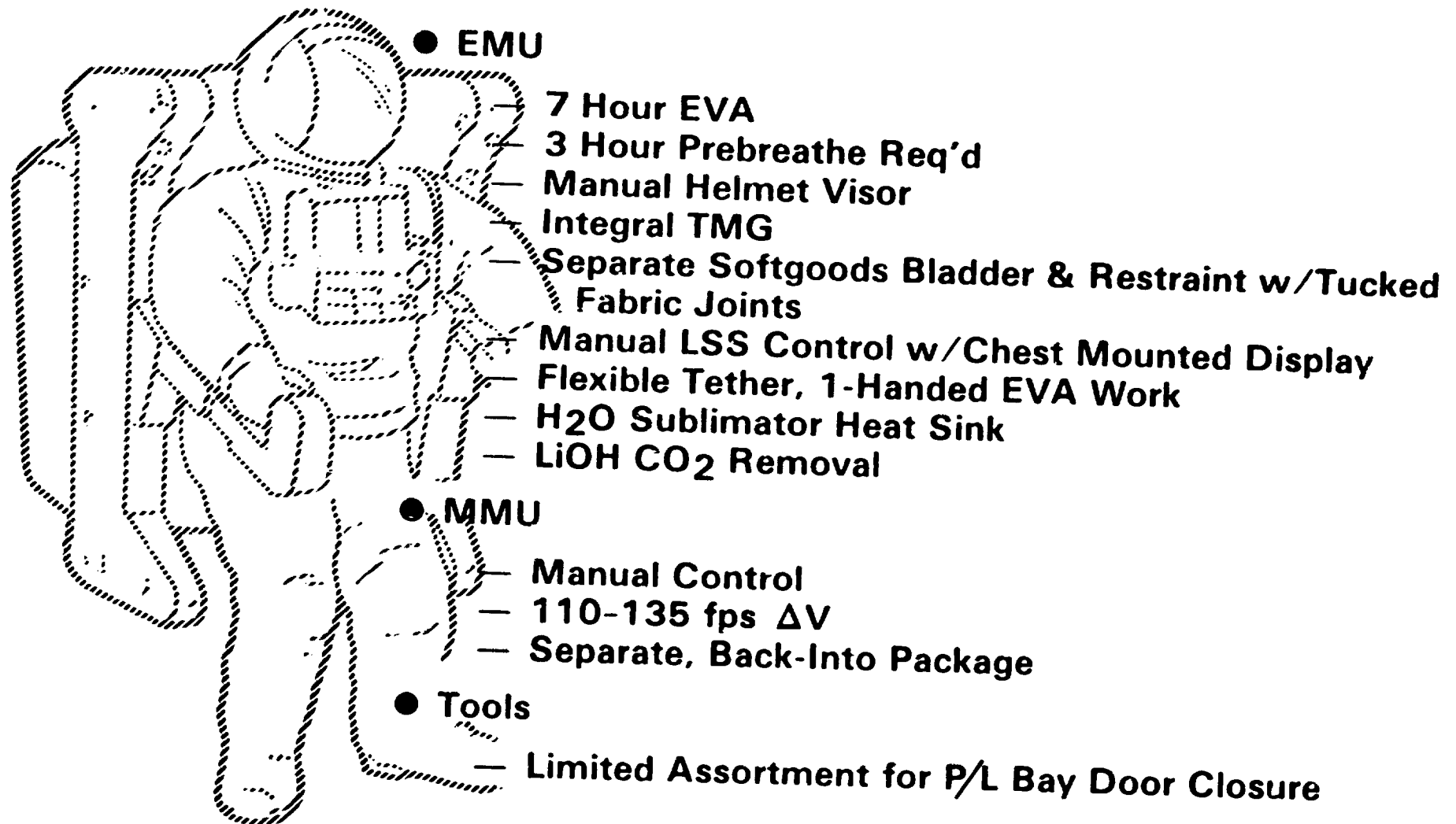
### 5. Service Operation Location

Payload bay and within RMS reach envelope.

### 6. Specific Service Tasks

- Normal Deployment (IV)
- Normal Snaring & berthing (IV)
- Contingency deployment (EVA release of stuck appendages).
- Inspection of Orbiter and payload. Access to interior may be limited by lack of hand-holds and removable panels.
- Module replacement, mate/demate electrical connectors, actuate switches & breakers.
- Service experiments, deploy booms, retrieve film.
- Contingency EVA - Repair of tiles, payload bay door closure and rescue.

## CHARACTERISTICS OF BASELINE EVA CAPABILITY



## CAPABILITY PACKAGE NO. 2

### 1. Capability

Routine Payload Servicing  
2-handed EVA Work Capability  
Eliminate Prebreathe

### 2. Equipment - Package No. 1 plus:

Hand tools, tool caddy, tram line, refuel facility, baffles, shields & adapters, decontamination facility, workstand and adhesive bond gun, wide angle helmet & rugged gloves.

### 3. Satellite Operation

Clean lenses & sensors, disarm subsystems, refuel.

### 4. Satellite Subsystems

ACS, payload

### 5. Service Operation Location

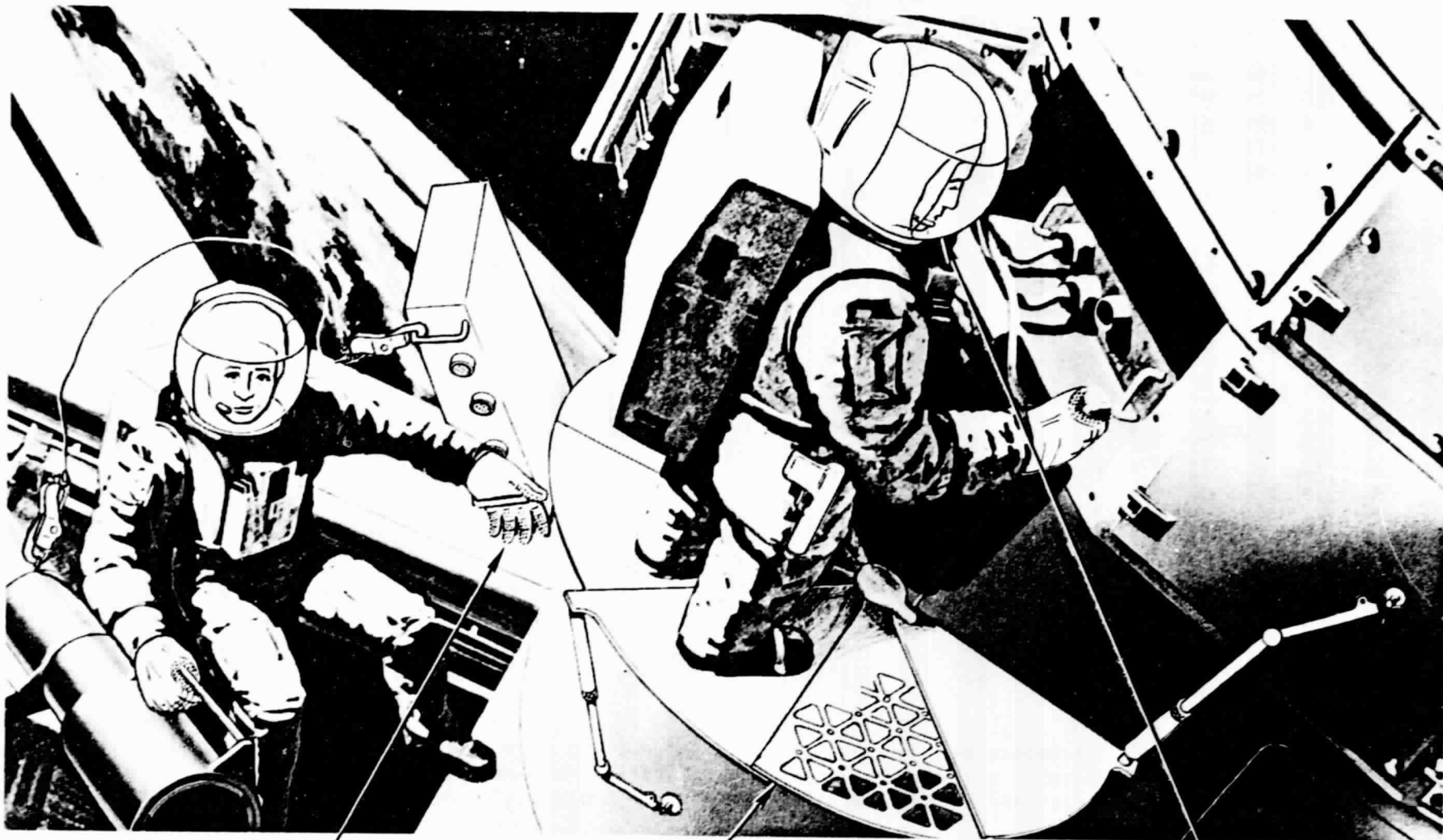
Payload bay & attached to RMS

### 6. Specific Service Tasks - Tasks of Package 1 plus:

- Refuel, connect/disconnect fluid lines, gage & distribute fluid quantities, actuate valves, vent pressure vessels.
- Shield pressure vessels & radiation sources.
- Clean lenses & sensors, refurbish surfaces.
- Trim away damaged or unwanted appendages, stow debris in payload bay.
- Decontaminate removed hardware.
- Install FSS adapter.
- Fold appendages.
- Tether & release unsupported hems.

## ROUTINE PAYLOAD SERVICING

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**Rugged  
High Tactility  
Glove**

**Portable  
Folding Workstand  
& Adhesive Bond Gun**

**Automatic Visor  
Wide Angle  
Helmet**

## REQUIRED TECHNOLOGY DEVELOPMENTS FOR CAPABILITY PACKAGE NO. 2

The following items of equipment listed for Capability Package No. 2 will require new technology development.

1. Wide Angle Helmet with Automatic Visor - A new helmet concept that permits wide angle viewing as the crewmember moves his head. Automatic visoring means that the visor's light transmissibility adjusts itself in accordance with the ambient light intensity. The crewmember need not interrupt a work task to change the visor setting by hand.
2. Rugged, High Tactility Gloves - A new EVA glove concept that combines ruggedness and high tactility. Modular construction makes the glove maintainable on-orbit.
3. Folding Workstand - To be easily attached to payload or satellite. Anchors crewmember's feet, permitting use of both hands for performing useful work.
4. Adhesive Bond Gun - Concepted as a simple-to-operate means for bonding attachment fittings to the payload, satellite or structure to secure the folding workstand or to provide tool/ equipment tether points.
5. Refuel Facility - An equipment rig, comprised of tanks, valves and lines to replenish satellite supplies of fuel, oxidizers and pressurant. Multi-tank fluid gaging and fluid detanking provisions are needed.

The following capabilities should also be developed for Capability Package No. 2.

1. Eliminate Prebreathe - Baseline EMU capability requires prebreathing pure O<sub>2</sub> for three hours before EVA. This represents an unacceptable complication for routine servicing, where EVA is to be considered the normal mode.
2. Decontamination - While normal satellite fuel system servicing should be leak-free, the possibility for inadvertently contaminating the spacesuit, and especially the gloves, should be recognized. Satellite fuels such as hydrazine vapor are both toxic and explosive. Hydrazine liquid can burn the skin chemically. Absorbent flammables, such as paper or cloth, can ignite spontaneously in air if they have soaked up liquid hydrazine. Fuels such as these must be kept out of the Orbiter cabin and airlock. Provisions for detecting and removing fuel residues prior to repressurizing the airlock are required.

### AUTOMATIC VISOR, WIDE-ANGLE VISION HELMET CONCEPT

The EVA helmet concepted to meet projected requirements is shown in the accompanying illustration. It consists of a single assembly composed of a clear, outer, polycarbonate plastic bubble secured to the EVA closure by a neck ring disconnect. This bubble provides the helmet structural integrity and pressure retention. The liquid crystal visoring panels, forming four vision zones, are bonded to the inside surface of the bubble like tiles. A miniature photo sensor, located in the middle of each visor panel, senses the intensity of ambient light falling on each visor panel, and causes an electronic control, located in the back of the helmet, to regulate the transmissibility of the visor panel accordingly. A more complete description is contained in Volume 2 of this report.

The basic technology development areas center about the liquid crystal visor panels and manufacturing cost reductions. Consequently, the technology development program emphasizes these aspects.

- Requirements Definition - Study the requirements to refine and expand them to give firm targets for guiding the liquid crystal development.  
Duration; 2 Months
- Liquid Crystal Development - Assess and develop the following aspects of liquid crystals.

Assess visible and IR transmissibility in the energized and unenergized state and develop liquid crystal materials to meet requirements. Assess need for supplemental coatings to finetune the liquid crystal transmissibility properties.

Reduce the response time for turn-on/turn-off cycles. Assess potential for pulse-width modulation of transmissibility.

Develop electronic controller circuitry.

Assess liquid crystal material as a potential contaminant within the ECWS, should breakage of liquid crystal panels occur. Assess medical and decontamination issues.

Develop total life capability to meet projected 10 year life of ECWS equipment.

Develop ability to fabricate liquid crystal panel with spherical curvatures.

Assess compatibility of projected solar reflective and anti-back reflectance coatings with projected bubble-to-visor bonding agents.

Duration; 18 Months

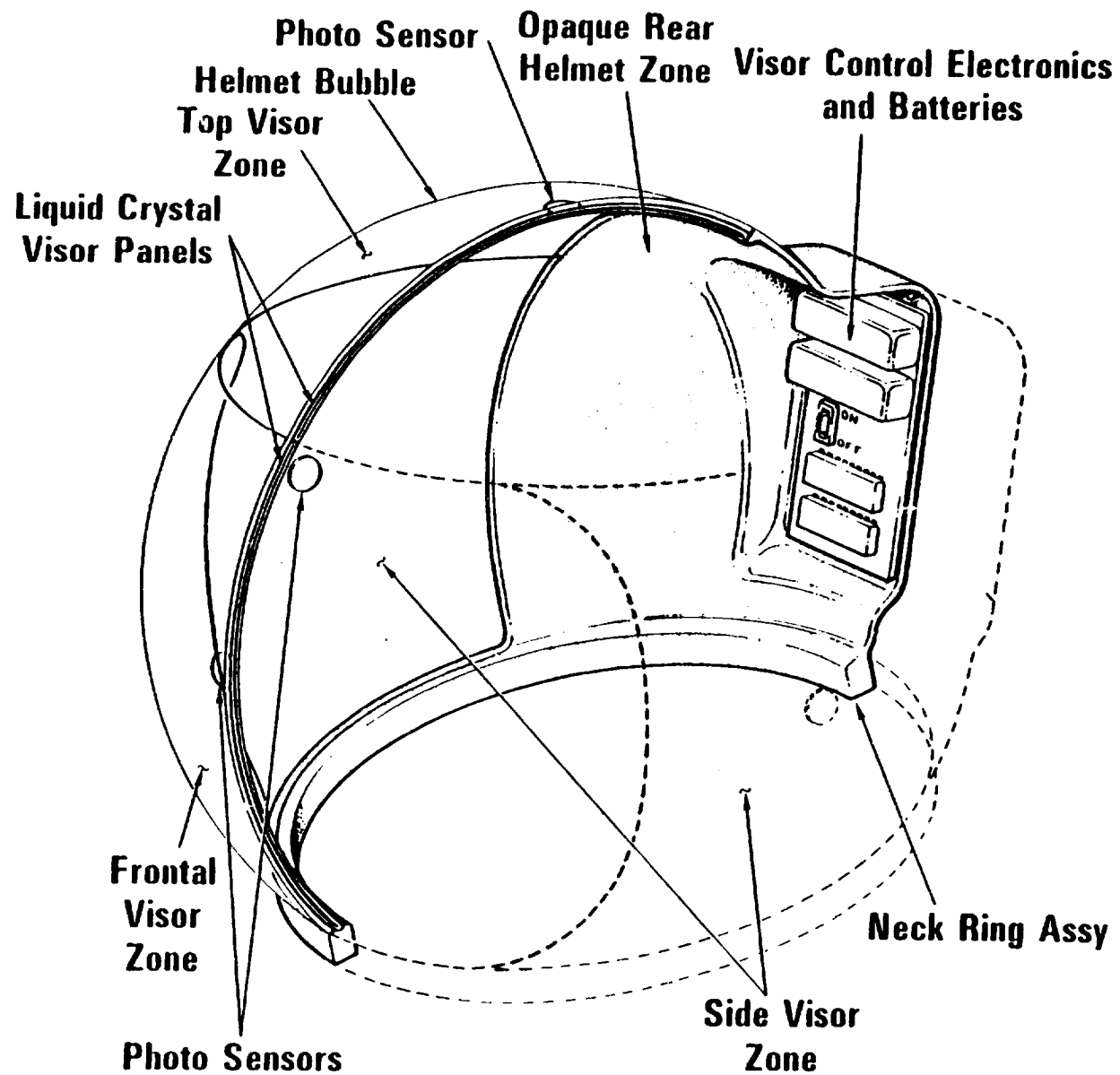
#### Automatic Visor, Wide-Angle Vision Helmet Concept (Continued)

- Helmet - Helmet fabrication techniques and materials bear investigation because the results may indicate functional and economic advantages of changing the present EMU helmet design and manufacturing process. The present manufacturing process for Shuttle EMU helmets uses press-polished polycarbonate sheets which are blow molded into a female mold. The resulting helmet is lightweight, reliable, adaptable to sun visors, and provides adequate visual range for Shuttle EVA. However, the present inspection process is highly critical in several respects causing a high helmet rejection rate, and thus causes the helmets to be expensive.

Investigation of the manufacturing process may indicate that injection molding would be cost effective, producing high quality helmets at low cost, once the process development and mold costs are amortized. A change in process would also permit economical implementation of a change in helmet shape to improve the donning easement and to increase the rearward field of vision.

During this investigation the use of other materials, such as new scratch resistant coatings or polysulfone is recommended to improve scratch resistance and high temperature resistance.  
Duration: 18 Months

## HELMET DESIGN CONCEPT





### PLZT GOGGLE CONCEPT

The PLZT goggle concept is a potential alternative to the liquid crystal visor. PLZT is a ceramic material of 65% lead zirconate and 35% lead titanate, with lanthanum replacing up to 9% of the lead. Sandia Laboratories has developed the material for use in a thermal flash protective goggle to protect the eyes of personnel from nuclear explosion flashes.

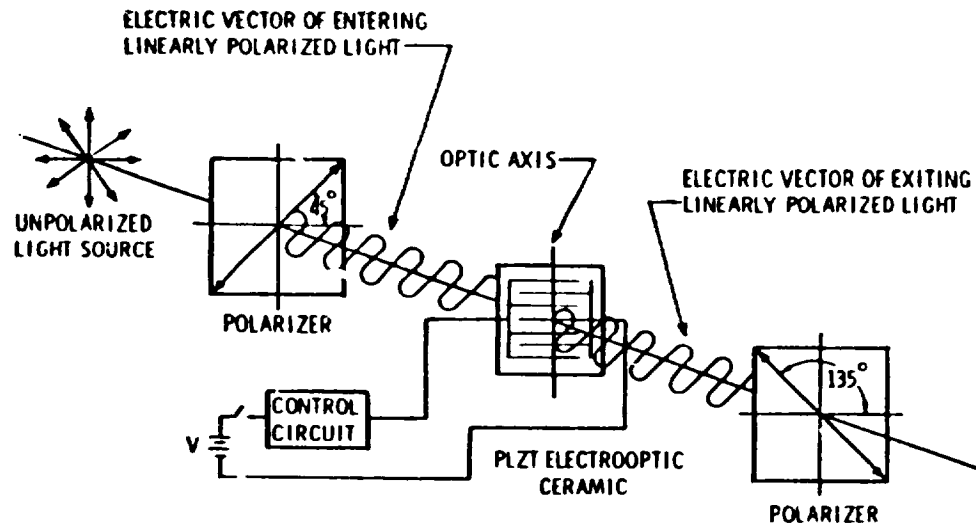
The functional schematic of the goggle lens is shown in the accompanying illustration. The device operates exactly as the well-known Kerr cell. The electrooptic wafer is sandwiched between two polarizers, and oriented so that its optic axis is at  $45^\circ$  to the polarizer axes. In the closed-state or "off" condition, there is no voltage difference between the elements of the interdigital electrode array on the surface of the ceramic wafer. Under these conditions the wafer is optically isotropic and does not affect the light which passes through it. The light is consequently blocked by the polarizer pair, as shown in Figure A.

In the open-state, or "on" condition, a voltage difference is applied to the electrodes to create birefringence in the wafer. In this case the wafer becomes optically anisotropic, and retards a component of the polarized light. As a result, the light leaves the wafer in a state of elliptical polarization, which enables some transmission by the second polarizer. When the correct voltage is applied, the wafer acts as a broad-band half-wave plate, and the light which leaves the wafer is linearly polarized but rotated by  $90^\circ$ . This is the maximum-transmissivity condition for the assembly, and is shown in Figure B.

The level of transmissivity may be continuously varied between the two extremes by controlling the amount of applied voltage, creating an electrically controlled variable density optical filter. A subtraction-color filter can be generated by using the device with a white-light source at voltages higher than the broad-band half-wave voltage.

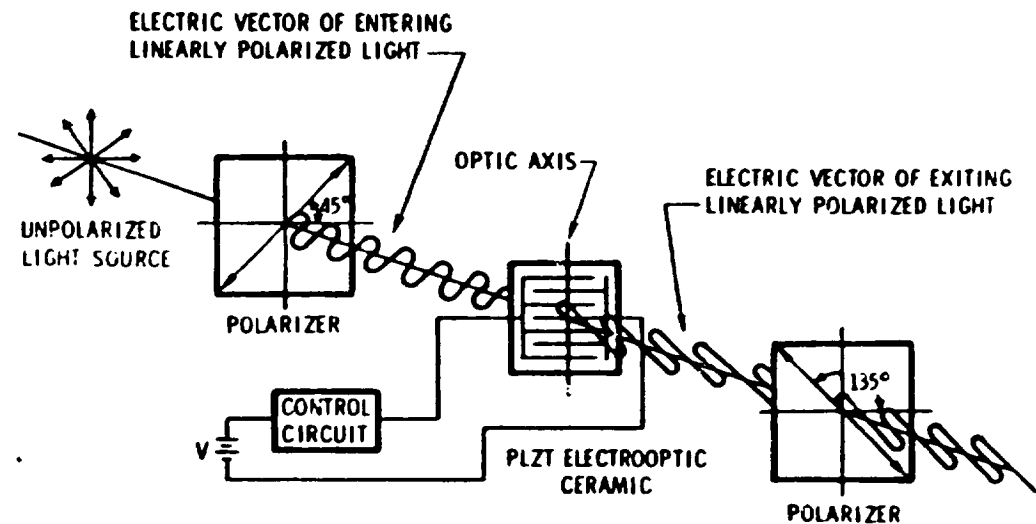
For the thermal flash protective device application, the device is typically operated in the fully-open state until a light hazard is detected by suitable sensors in the control circuit. When this occurs, the PLZT wafers are rapidly discharged by a silicon-controlled rectifier (SCR), and the goggles revert to the closed state. When the threat is removed, the wafers are re-energized and the open state is recovered. In practice, the hazardous light threat may decay very gradually. In this case, the wafer can be recharged in a gradual fashion to maintain a continuous safe level of illumination through the lenses.

A). SCHEMATIC OF SINGLE-STAGE DEVICE  
"OFF" CONDITION



**Schematic operation of the  
PLZT single-stage device in  
a) the closed state and  
b) the fully open state.**

B). SCHEMATIC OF SINGLE-STAGE DEVICE  
"ON" CONDITION



# PLZT Goggle Concept (Continued)

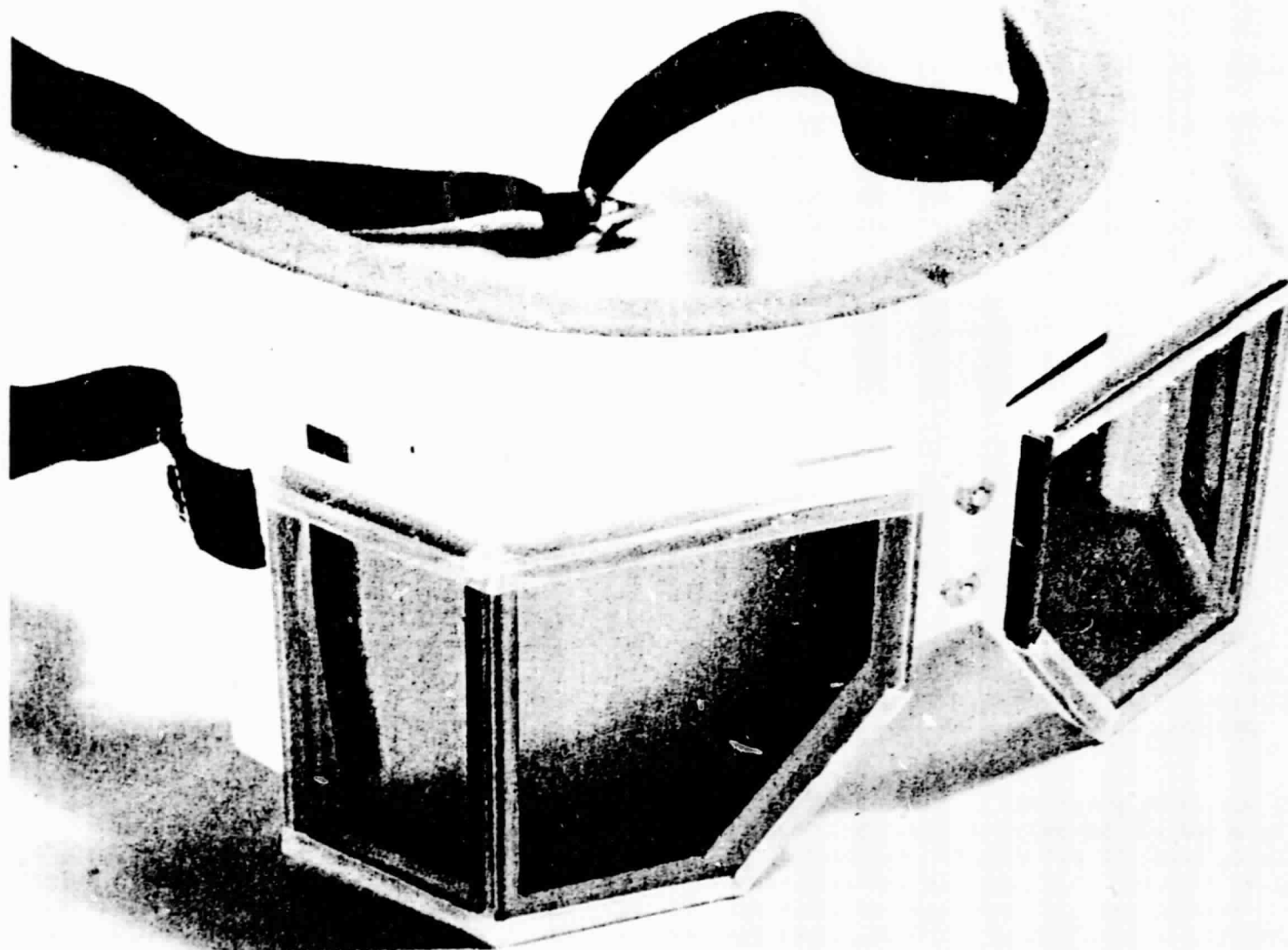
Evaluation of the goggle concept against the requirements defined for the liquid crystal helmet show the following:

	EMU EVVA Reqt.	LC	PLZT
Optical Transmissibility	Open 80% Closed 7%	85% 15%	37% .003%
Shape	Curved, 5 in. Rad	Flat	Flat
Temp Range	40°F to 80°F	18°F to 170°F	45°F to 55°F
Switching Time	10 msec	150 to 600 msec	150 sec
Life	90,000 hrs. 2,000,000 cycles	50,000 hrs. TBD cycles	1,000,000 cycles
Actuation Voltage		3-15 VAC	1,400 VDC

From the above it is apparent that both liquid crystal and PLZT materials do not precisely meet present EMU EVVA requirements, but both appear worthy of further investigation. Preliminary indications are that spherical liquid crystal panels are feasible, although plate spacing will have to be controlled. Spherical grinding of PLZT is considered impractical at this time. Hence PLZT is expected to be limited to goggle or spectacle use. Prescription PLZT spectacle lenses have been fabricated, hence use of PLZT spectacles or goggles within a clear helmet hubble may be feasible.

## NON-HELMET MOUNTED GOGGLE MOCK-UP

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### RUGGED HIGH FACILITY GLOVE CONCEPT

The ECWS EVA glove concept relies heavily on the best features of existing NASA EVA glove designs, as well as adding some new features to make it suitable for EVA construction use. In general the ECWS EVA glove concept consists of a modular, molded, single wall laminated glove structure that integrates the pressure retention bladder and the restraint layers into a single wall construction. Thermal insulation to accommodate work piece surface touch temperature extremes of -180°F to +200°F is included in the basic glove. Solar radiation protection is provided by cover layers that are tailored to the particular construction EVA orbit. The general features of the ECWS EVA glove concept are shown in the accompanying illustration. A more complete description of the concept is contained in Volume 2 of this report.

The new technology development requirements for the ECWS EVA glove consists of improving life and compatibility with tools, as well as providing thermal protection and protection from solar radiation and workplace hazards. Accordingly, the ECWS EVA glove new technology program consists of specific areas of joint, laminate and palm development to achieve the required glove characteristics. This is followed by a glove prototype evaluation phase.

- Joint and Laminate Development - Joints to be developed are the wrist and metacarpal joints. It is recommended that a two-axis flat pattern joint be developed for the wrist, rolling convolute joints be developed for the thumb and finger first metacarpal joints, and mini convolutes be developed for the remaining thumb and finger metacarpal joints. Emphasis should be placed on achieving 500,000 cycle life on all glove joints, while minimizing operating torque and operating at 8 psi.

Develop laminated fabric construction that includes the wire mesh reinforcement in the interjoint sections. Develop the insulating pins and the process for molding them into the fabric laminate, determining the best combination of length, diameter and spacing. Develop integral thermal radiation shielding within the laminated structure.

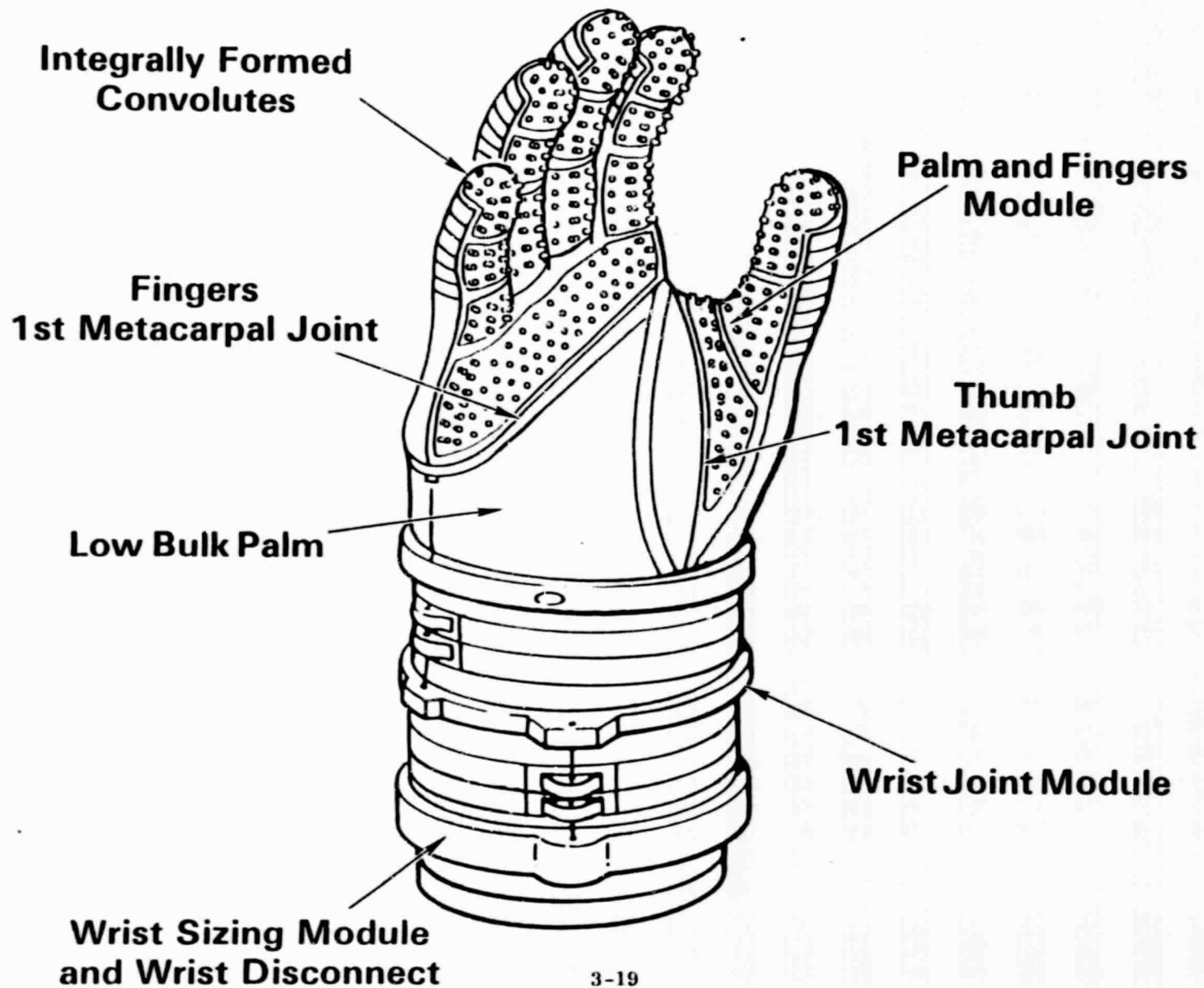
- Palm Development - In parallel with the joint and laminate development, develop a minimum bulk palm. Emphasis should be placed on comfortable gripping of tools and providing an adequate structural base for the thumb and finger first metacarpal joints.

Duration: 18 Months

- Prototype EVA Glove - Design, construct and test a prototype glove embodying the features developed above. The glove could be evaluated on earth, in a glove box, or in space, as a Shuttle flight experiment. Incorporate any changes required in the design of flight hardware.

Duration: 12 Months

## GLOVE DESIGN CONCEPT



## PORTABLE WORKSTAND

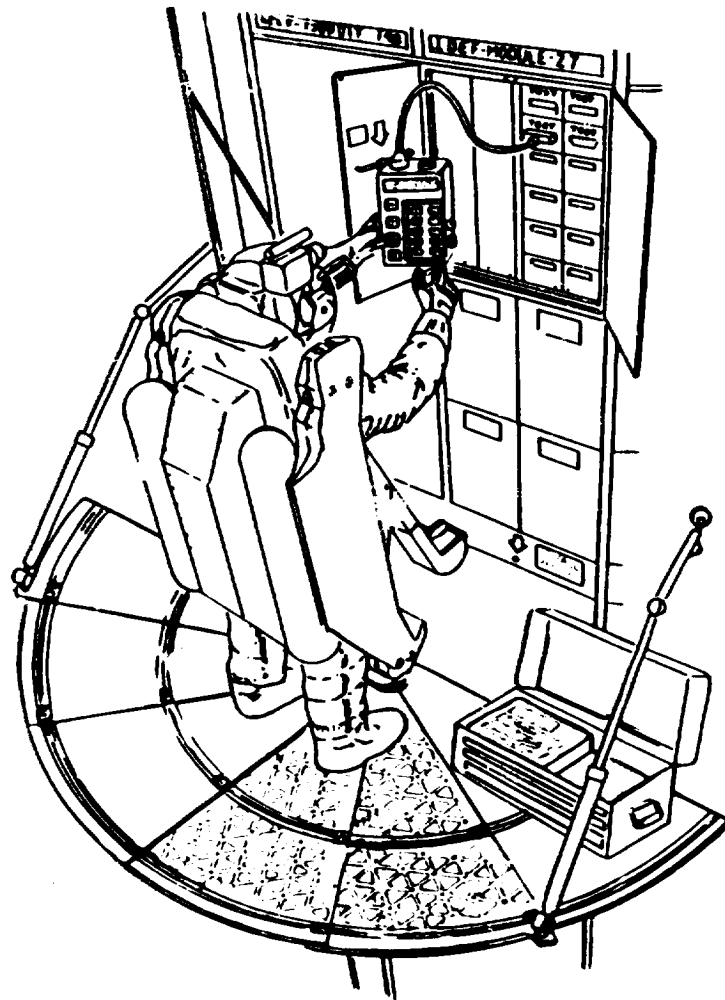
The portable folding workstand provides crewmember restraint at worksites. The concept uses "astrogrid", developed for Skylab, to secure the feet. The crewmember then retains use of both hands for performing work and can bend and turn without disengaging the feet. The concept also provides a "walk-around" capability, permitting earthlike access to tools, supplies and replacement modules. The workstand is two sided, permitting access to large work sites. It folds into a flat package for convenient carrying and stowage. It is enclosed to solid structure by adhesive bonding, described subsequently in this report.

The portable workstand concept embodies new technology in the structure attachment area. All other elements represent new applications of existing ideas. Therefore, the technology development program emphasizes element development followed by prototype development.

- Element Development - Develop the articulated mounting arms, evaluating and selecting friction materials and adhesives to ensure that the platform will support the design loads.  
Duration: 12 Months
- Prototype - Design and evaluate a prototype portable workstand to identify problems associated with integration. Evaluate the prototype either under water or as a Shuttle flight experiment.  
Duration: 18 Months

## PORTABLE WORKSTAND CONCEPT

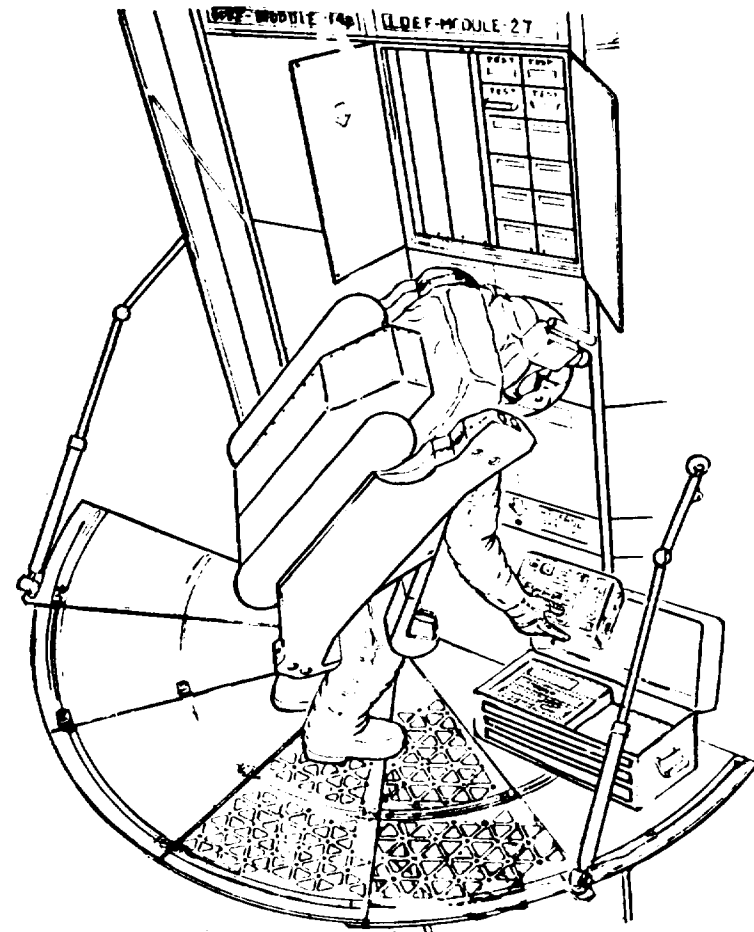
- 2-Hand Work Task Capability
- Astrogrid Foot Restraint Grounds Force & Torque Reactions
- No Waist Restraint Required





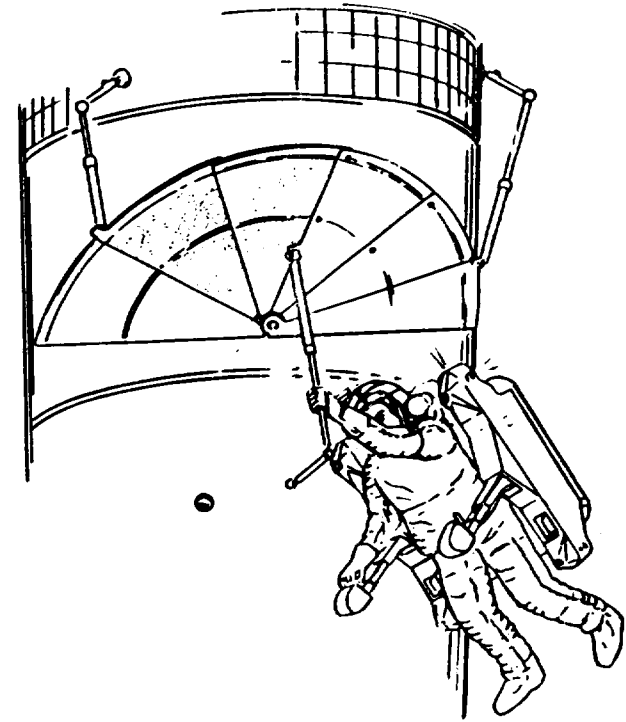
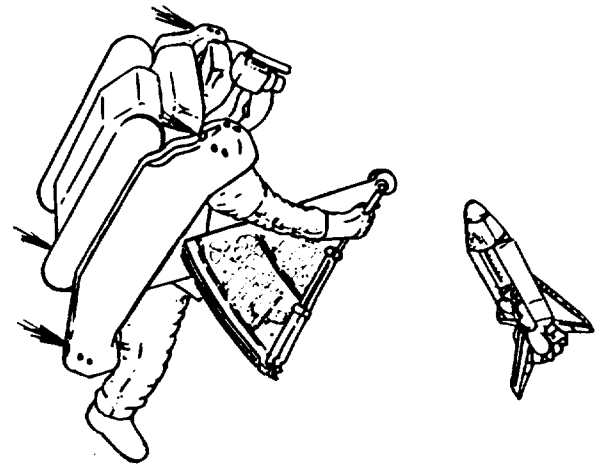
## PORTABLE WORKSTAND CONCEPT (Continued)

- Earthlike Task Capability
- Maximum Bend, Reach, Turnaround Capability
- 29 Ft<sup>2</sup> Walkaround Area — Each Side
- Tool Tether Points
- Work Supply Attachment Points



## **PORTABLE WORKSTAND CONCEPT (Continued)**

- **Six Segment Folding Design**
- **One Person Set-Up**
- **Mounts to Any Solid Structure**
- **No Special Mounting Provisions Required on Structure**
- **Compact When Folded —  
52 In. x 27 In. x 6 In.**
- **Light Weight — 95 Lbs**



### WORKSTAND ATTACHMENT

Adhesive bonding is a candidate means for attaching a portable workstand to solid structure. Adhesive bonding, using thermoplastic adhesives, permit quick attachment of the workstand to the worksite. In actual operation an adhesive hand gun could be used to bond several attachment fittings to payload structure. The workstand would be then attached to the fittings. At completion of the task the workstand would be released from the fittings. At completion of the task the workstand would be released from the fittings. The bond between the fittings and structure would be reheated and the fittings released for reuse, leaving no scar at the structure.

The concept presented for fuse bonding workstand attachment fittings to payload structure is called TAGG - Thermally Activiated Glue Gun.

### TAGG - THERMALLY ACTIVATED GLUE GUN

TAGG is a hand held, gun-like tool concept for fastening workstand attachment fittings to payload structure worksites. TAGG uses electric induction heat to melt adhesive which has been preapplied to the attachment fittings. The tool has storage capacity for four fittings, which is more than sufficient for securing the workstand to one worksite.

To attach a fitting the crewmember approaches the worksite and selects the fitting location. Using push buttons and a trigger control he heats the fitting until the adhesive melts, expels the fitting and holds it in position for a few seconds until the adhesive cools and solidifies. At this point the fitting can be used to attach the workstand. To remove a fitting the TAGG is placed over the fitting and then heat is applied. When the fitting becomes loose, TAGG retracts the fitting.

Technology development centers around adhesive selection or development. Thermoplastics must be found that can be applied to surfaces between -180°F and +200°F and that retain adequate strength in high IR environments, up to +450°F. In addition it would be desirable if any adhesive remaining on a structure surface after removal of a fitting would sublime in sunlight in approximately one week. Thus the attachment would truly be "no scar".

Duration: 18 Months

Additional technology development is concerned with adhesive heating and will human factors. A prototype program is recommended to resolve such issues prior to design of a flight item.

Duration: 18 Months

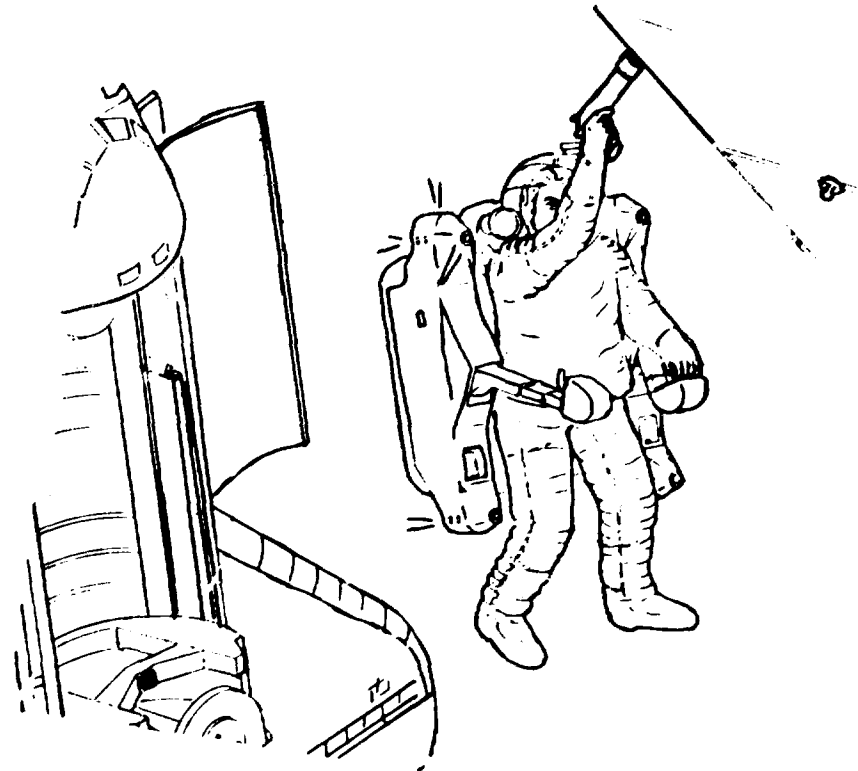
# **THERMALLY ACTIVATED GLUE GUN (TAGG)**

## **Requirements:**

- Provides Hitch Points for Workstand Mounting**
- No Attachment Scars**
- Minimum Number & Weight of Hitch Points**
- Easy to Use**
- Light Weight**

## **Features:**

- Provides Quick, Strong Bond**
- Firmly Attaches Multipurpose Hitch Point**
- Fast Remelt Capability**
- No Reaction Forces**
- One Hand Operation**



### SATELLITE REFUEL FACILITY

The refuel facility replenishes satellite fuel, oxidizer and pressurant supplies. When refuelling is complete, the flight crew must have assurance that the satellite tanks have been filled to proper levels and no gross fluid leakage is occurring.

Additional capability should include detanking, residual fluids and purging a satellite subsystem prior to replacing modules or fluid lines, or performing other repairs in orbit that require violating the integrity of the fluid system.

Technology issues consist of fluid gaging, fluid distribution and gross leak detection in zero-g. Applicable technology exists in ground-based fuelling facilities and in spacecraft fluid systems. Therefore, just a short, preliminary design phase is recommended prior to design of a flight system.

Duration: 6 Months

## DECONTAMINATION FACILITY

A decontamination facility may be required to insure that no fuel or oxidizer residues enter the cabin or airlock atmosphere on the space suit. The facility should include contaminant detection as well as removal capability.

However, such a facility should only be a backup. Procedures to avoid contamination and EVA equipment that does not absorb contamination should be the primary measures to prevent contamination of the cabin atmosphere.

The first objective of technology development, contamination prevention, is to minimize the ability of the SSA to absorb propellant contaminants, and to assess the hazard potential of any residual contamination. Means for deleting contaminants should be developed. Simple procedures for removing dangerous or objectionable levels should be developed.

Duration: 12 Months

If simple means, such as wipes, overgarments, overgloves or exposure to the sun do not prove feasible or adequate, then more sophisticated means may be required. A study to identify these additional means is recommended. It should be conducted in parallel with the effort to minimize the contaminability of the SSA.

Duration: 6 Months

### CAPABILITY PACKAGE NO. 3

1. Capability

Perform Structural Repair

2. Equipment - Package No. 2 plus:

Hand-Held Power Tool

Fuse-Bond Hand Tool

3. Satellite Operation

Trim away damaged structure & appendanges.

Fabricate and install repair structure.

4. Satellite Subsystems

Payload bay & attached to RMS

6. Specific Service Tasks - Tasks of Package No. 2 plus:

- Shield jagged edges
- Smooth rough edges
- Trim away damaged material
- Make fastener holes
- Tighten & loosen fasteners rapidly
- Bond/weld new structure into place
- Measure length, gage straightness
- Straighten deformed metal



## PREBREATHE ELIMINATION

Present EVA requires the crewmember to prebreathe pure O<sub>2</sub> for approximately three hours before depressurizing the airlock. Any inhalation of nitrogen during prebreathe sets back the denitrogenation process, requiring even more prebreathe time. Present EMU donning procedures are complex owing to the requirement to maintain a denitrogenated state during donning. Donning procedures involve using two portable O<sub>2</sub> systems, a change-over from breather mask to mouthpiece, an elastomer cuff to purge nitrogen from the suit and a separate O<sub>2</sub> supply and valve to purge the helmet of nitrogen. Holding one's breath and cycling the PLSS fan are also required by the donning procedures.

Eliminating prebreathe is a stated goal of the ECWS study program. Construction operations will be conducted from a construction habitat. ECWS will support construction EVA. The habitat and ECWS are not tightly constrained by existing hardware, except for Orbiter resupply. ECWS study program recommended using 9 psia in the habitat and 4 psia for construction EVA. It appears feasible to manage Orbiter cabin issues to be compatible with resupplying a 9 psia habitat.

However, satellite service presents a different set of conditions. Satellite operations will be conducted from the Orbiter itself. Spacelab and experiments may be present, and their pressure levels, material flammability and air cooling requirements require consideration. The existing EMU will support satellite service EVA, at least initially. Other system elements also currently exist or are being planned, such as the Orbiter, Spacelab and experiments. Eliminating prebreathe is expected to require some combination of equipment changes and modification to EVA operational and training procedures.

The best choice is not presently clear for eliminating prebreathe from the existing Orbiter-Spacelab-EVA-experiments system. A study is recommended to identify and evaluate hardware impacts and EVA issues to recommend the best choice.

Duration: 6 Months

### REQUIRED TECHNOLOGY DEVELOPMENT FOR CAPABILITY PACKAGE NO. 3

The following items of equipment listed for Capability Package No. 3 will require new technology development:

- Hand-Held Power Tool - A multi-purpose power tool that drives fasteners, cuts material and makes holes.
- Welding/Bonding Tool - A tool for joining material sections together when performing structural repairs.

## HAND-HELD POWER TOOL

The hand-held power tool consists of a handle-driver module to which individual tool modules are attached. The tool modules provide drilling, socket wrench, screwdriver, grinding wheel, wire brush and circular saw functions. These are all rotary motion functions. Other tool modules provide shearing, hacksaw, pop rivet, filing, stapling and material nibbling functions, which use reciprocating motions.

The handle-driver module concept contains two separate drive trains which are driven by a permanent magnet DC motor. Magnetic clutches engage the desired drive trains. Two rechargeable Ag-Zn batteries contained in a separate pack power the motor. By using one or both batteries two speed-torque characteristics are available. A voltage control provides additional speed reduction in both speed-torque characteristics. The resulting flexibility in speed-torque characteristics makes the handle-driver module capable of powering all of the tool functions identified above.

Cooling provisions depend upon tool use duty cycles. Radiant cooling from the tool itself is sufficient for intermittent duty. Continuous duty would require active cooling, integrated perhaps into the ECWS LCVG cooling loop or into the battery pack.

The tool modules resembles earth tools for the most part. However, two features are different. The first involves fastener drivers. To avoid having to handle individual wrench sockets to accommodate different nut or bolt sizes, a single, adjustable socket has been conceived, as shown in the accompanying illustration. This socket concept is expected to cover the size range normally provided by approximately nine fixed size sockets ranging from 1/2 in. to 1 in. A related concept involves screwdriver bits. Individual bits are stored in a magazine, which automatically installs the selected bit without requiring individual handling. Both concepts avoid the possibility of losing loose, individual tool elements.

Debris collection is the second feature. Operations that remove material, such as drilling, sawing or grinding are expected to require debris collection means. One approach is to use the kinetic energy of the particles to enmesh them in a moving bristle belt. The belt transports the particles to a collector. By bending and releasing the bristles in a "twanging" fashion releases the particles and propels them into the collector.

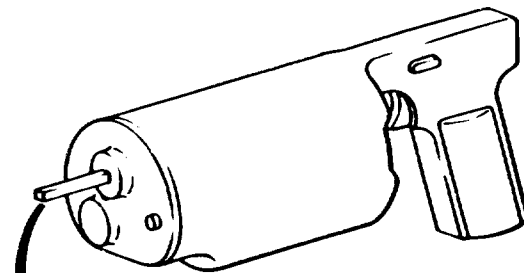
# HAND-HELD POWER TOOL CONCEPT

- **Rotary Motion**  
(Clockwise + Counterclockwise)

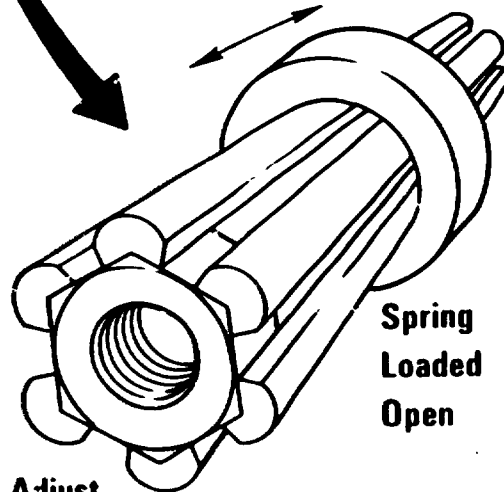
- Drill
- Socket Wrench
- Circular Saw
- Fastener Driver

- **Reciprocating Motion**

- Saw/File
- Shears
- Riveter



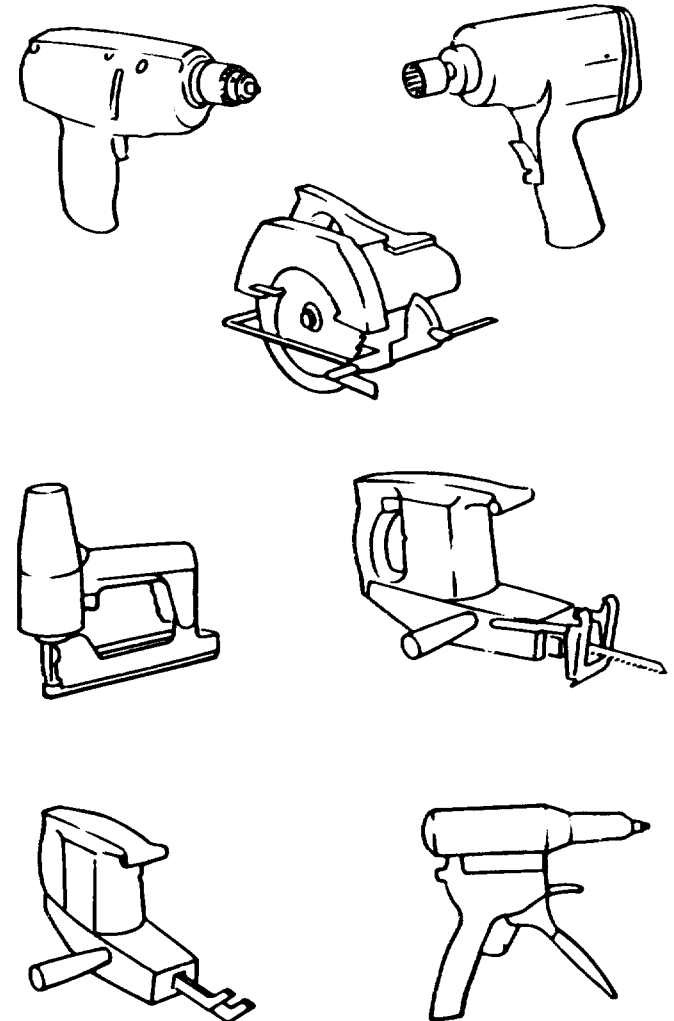
Move Collar Back & Forth Under Power



Spring Loaded Open

Spring Fingers Adjust to Nut/Bolt Head Size

**Overall Nut/Bolt Driver**



### Hand-Held Power Tools (Continued)

The powered tool adapter is a moderately complex packaging of simple, straight-forward mechanical elements. The chief development problems will be to fine tune the design to maximize the utility of the powered tool adapter and to facilitate its assembly and repair. Accordingly, the technology development program emphasizes refinement of the concept followed by a series of two prototype design and evaluation iterations from which the flight design can be evolved. Evaluation can be performed on the bench, under water, in a space chamber or in space as required. The highlights of the recommended technology program are as follows:

- Concept Refinement Study - Evaluate the projected space structures to identify the required ranges of all motions and forces required for assembly, alignment, checkout and actuation. Expand the powered tool adapter requirements to conform with the results of the evaluation. Develop several alternative concepts which meet the above requirements.  
Duration: 6 Months
- Breadboard Prototype - Design, fabricate and evaluate a breadboard prototype of the powered tool adapter using commercially available components where possible. Integrate all the desired and required functions into one unit. Identify problem areas and solicit solutions for incorporation into a prototype design. Define the basic arrangements of switches and dials necessary to perform required powered tool adapter functions. Prepare the design of the general concept configuration which will ensure that comfort and utility requirements are met.  
Duration: 9 Months
- Prototype Development - Design, fabricate and evaluate the prototype. Ensure that all functional objectives are achieved with a unit as compact as possible. Consider the impact of various hand sizes and reflect this in the design. Evaluate and select bearings, seals and materials for use in the flight version. Evaluate on the bench and in use with a sea level, pressurized suit. Also consider using the prototype in simulated underwater construction activity and as a flight experiment.  
Duration: 18 Months

## WELDING/ADHESIVE BONDING

Materials used in satellite structure includes aluminum, magnesium and filament reinforced composites. Repairing structural damage is expected to require both welding and adhesive bonding capability, depending on the materials and extent of damage. Anticipated repair processes include laser and electron-beam welding for metals and fuse bonding for thermoplastics, where weld strength approaching the original material strength is required. Processes that rely on puddling a molten material into the damage zone, such as arc welding, brazing or soldering probably will not be used owing to problems of spattering and controlling the liquid interfaces in zero-g. Adhesive bonding can be considered for lower strength repairs to both metallic and non-metallic materials.

It is anticipated that fuse bonding of non-metallic and adhesive bonding of both metallics and non-metallics will be employed significantly more frequently than welding of metallics. It is recommended that a study be conducted to determine if enough metal welding will be performed to warrant developing welding equipment.

### Duration: 6 Months

Since extensive adhesive bonding and fuse welding is anticipated, developing a single tool performing these two functions is recommended. Technology development is required in two areas. The first area is to identify candidate adhesives for application to surfaces at from -180°F to +200°F. The second area is to design and manufacture a prototype a tool system to apply the selected adhesive. Because application of adhesives with heat is anticipated, it is expected that the fuse bond and adhesive bond capabilities can be integrated into a single tool.

### Duration: 24 Months

## CAPABILITY PACKAGE NO. 4

### 1. Capability

Achieve Mature Satellite Service Capability

### 2. Equipment - Package No. 3 plus:

Subsystems diagnosis and checkout kit  
Leak detection kit  
Fluid isolation kit  
Fluid system refill kit

### 3. Satellite Operation

Fluid system repairs  
Electronic System diagnosis and checkout, minor electrical repairs

### 4. Satellite Subsystems

Radiator subsystem, all electronic/electric subsystems

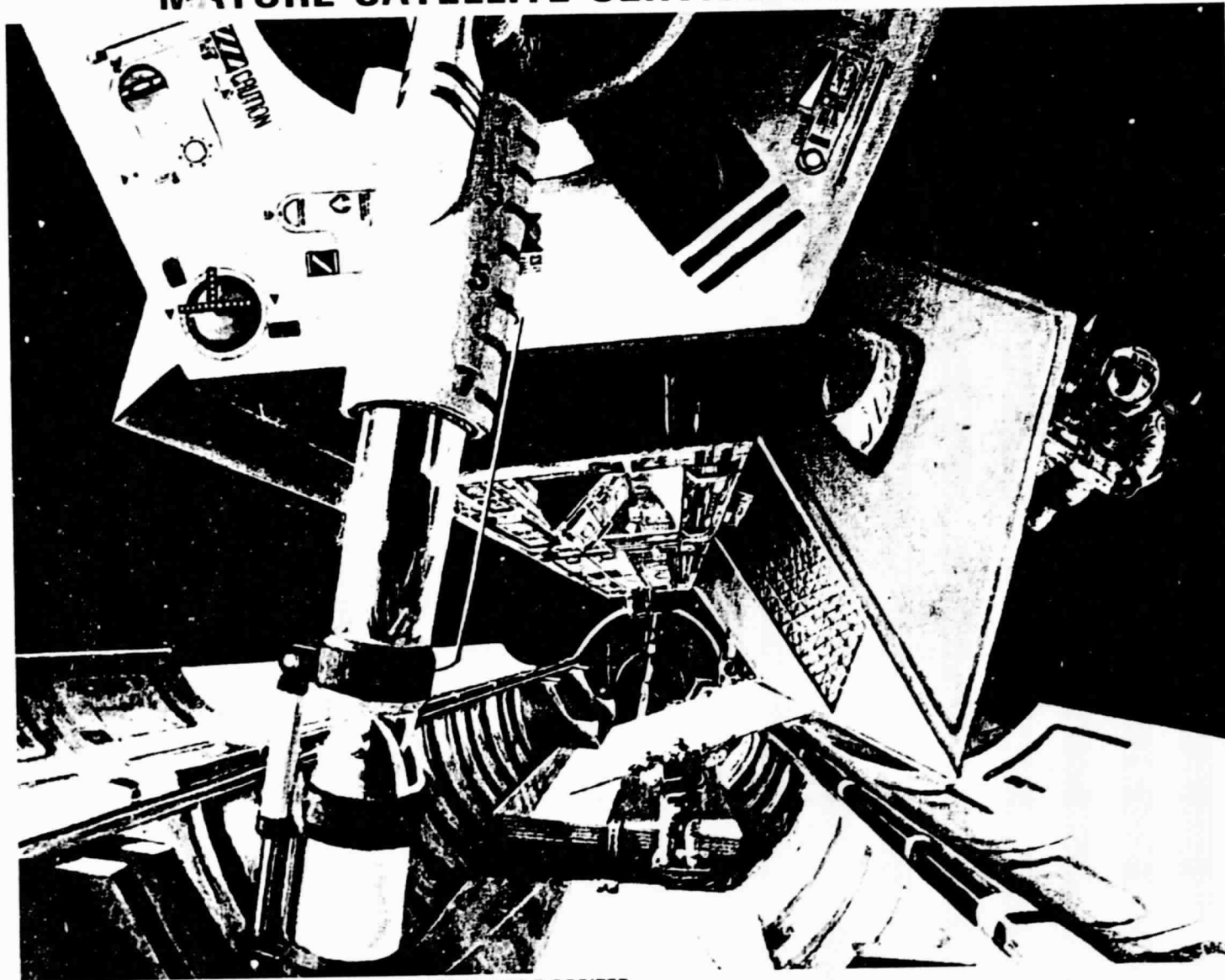
### 5. Service Operation Location

In payload bay or on RMS

### 6. Specific Service Tasks - Tasks of Package No. 3 plus:

- Repair of leaking fittings
- Replace damaged tubing
- Straighten bent electrical connector pins
- Repair damaged electrical harnesses
- Detect fluid leakage
- Check subsystem performance
- Calibrate sensors
- Refill fluid subsystem

## MATURE SATELLITE SERVICE CAPABILITY



AN OUT-THE-WINDOW VIEW OF SHUTTLE ORBITER CARGO BAY EVA OPERATIONS. The EVA crew uses established operational capabilities, tested support equipment and validated procedural techniques in accomplishing payload mission objectives.



#### REQUIRED TECHNOLOGY DEVELOPMENT FOR CAPABILITY PACKAGE NO. 4

The following items of equipment listed for capability package No. 4 will require new technology development.

- Subsystems Diagnosis and Checkout Kit - A portable, computerized test set for evaluating the condition of satellite electrical and electronic subsystems.
- Fluid Isolation Kit - A portable kit capable of isolating fluids within a satellite subsystem to prevent uncontrolled fluid loss when replacing subsystem equipment.
- Leak Detection - Portable equipment capable of indicating fluid leakage. This capability is required for verification of fluid subsystem integrity after completion of repair work.
- Fluid System Refill Kit - Equipment capable of refilling liquid cooling loops.

## SUBSYSTEMS DIAGNOSIS AND CHECKOUT KIT

The subsystems diagnosis and checkout kit concept is a portable, computerized test set capable of generating test signals and interpreting subsystem responses in order to check out satellite subsystems and diagnose subsystem problems. The kit is programmable in flight with diagnostic routines, developed on earth, for individual satellite subsystems being checked out. Routines for a particular satellite may be read into the diagnostic kit from a cassette, or could be contained in a plug-in "PROM" module.

In use kit probes, cable breakout adapters or diagnostic output plugs would be connected to the appropriate satellite subsystem wiring. The kit would then step through diagnostic routines, identifying normal and out-of-spec conditions. Instructions to the EVA crewman would also be generated, such as reconfiguring the test connections.

The diagnosis and checkout kit is essentially a space flight version of existing computerized automotive diagnostic systems and aircraft flight system condition monitors. The primary development issues will be software and equipment packaging. Software requirements must be defined for the projected population of satellites and their subsystems to be serviced. This will drive definition of computer capability. Techniques for packaging for operation in space are expected to be drawn from existing satellite electronic subsystem design.

A study to define software requirements is recommended as a first step. Subsystems of existing and projected satellites should be analyzed to identify types and variations, and then broad diagnostic strategies should be conceived and evaluated.

Duration: 1 year

Develop software using a 1-g prototype system following definition of software requirements.

Duration: 18 months

## FLUID ISOLATION KIT

A need is foreseen to be able to replace malfunctioned valves and other fluid subsystem components without detanking or purging the entire fluid subsystem. It would be desirable to isolate fluid under pressure in some portion of the subsystem while an adjacent portion of the subsystem was opened for repair.

An approach for liquid isolation was used for Apollo ground servicing, namely to freeze a section of liquid line using liquid nitrogen. In use LN<sub>2</sub> from a portable source flowed through a cuff surrounding a liquid line, freezing a plug of liquid inside the line. The line could then be cut or disconnected downstream of the plug. The main technology issue in adapting this concept to space flight is to make it workable in zero-g.

A need may also exist to isolate high pressure gas. This is a difficult requirement owing to high pressures involved and lack of a liquid medium to freeze. However, it may be possible to freeze a plug in the line using liquid helium. In use LHe would flow through a cuff surrounding the gas line. A controlled leak would be introduced in the gas line downstream of the cuff. As the gas passes down the line, it would freeze at the cuff, gradually blocking off the line. Cessation of flow at the controlled leak would indicate that line was completely frozen. Feasibility of this approach would have to be demonstrated in one-g, and then a flight version of the equipment would have to be developed.

Duration: 18 Months

## LEAK DETECTION

Leak detection will be an important capability in verifying the integrity of fluid subsystem repairs. Two concepts may be feasible, namely IR absorbtion and mass spectrometry.

An IR absorbtion concept consists of placing an IR detector cell behind an area to be tested and then shining an IR beam through an area of suspected leakage onto the IR sensor. A beam splitter would be used to illuminate a similar sensor with a reference beam that is not absorbed. A difference in the two IR signals would indicate fluid leakage. Special comparison circuitry could be preprogrammed for both the leakage fluid and the beam source-to-sensor distance.

A mass spectrometry concept consists of placing a plastic cuff around an area of suspected leakage to capture molecules of escaped fluid. A mass spectrometer probe inserted into the cuff would ionize some of the molecules and accelerate them toward a cathode plate. Upon impact with the plate the electrons stripped away during ionization would be replaced. The presence of cathode current would indicate leakage.

Both concepts are based upon well proven technologies. A feasibility study is recommended to identify the optimum concept. This should be followed by a prototype development phase to solve problems prior to starting the flight hardware program.

Duration: 18 Months

#### FLUID SYSTEM REFILL KIT

Fluid system refill service may be required for those satellites employing liquid cooling loops. This system would be similar to the refuelling facility described in capability package No. 2. Fluid system refill capability should include detanking residual coolants, refilling the loops and gaging the quantity of fluids added to the coolant loops.

Technology issues are the same for the refuel facility.

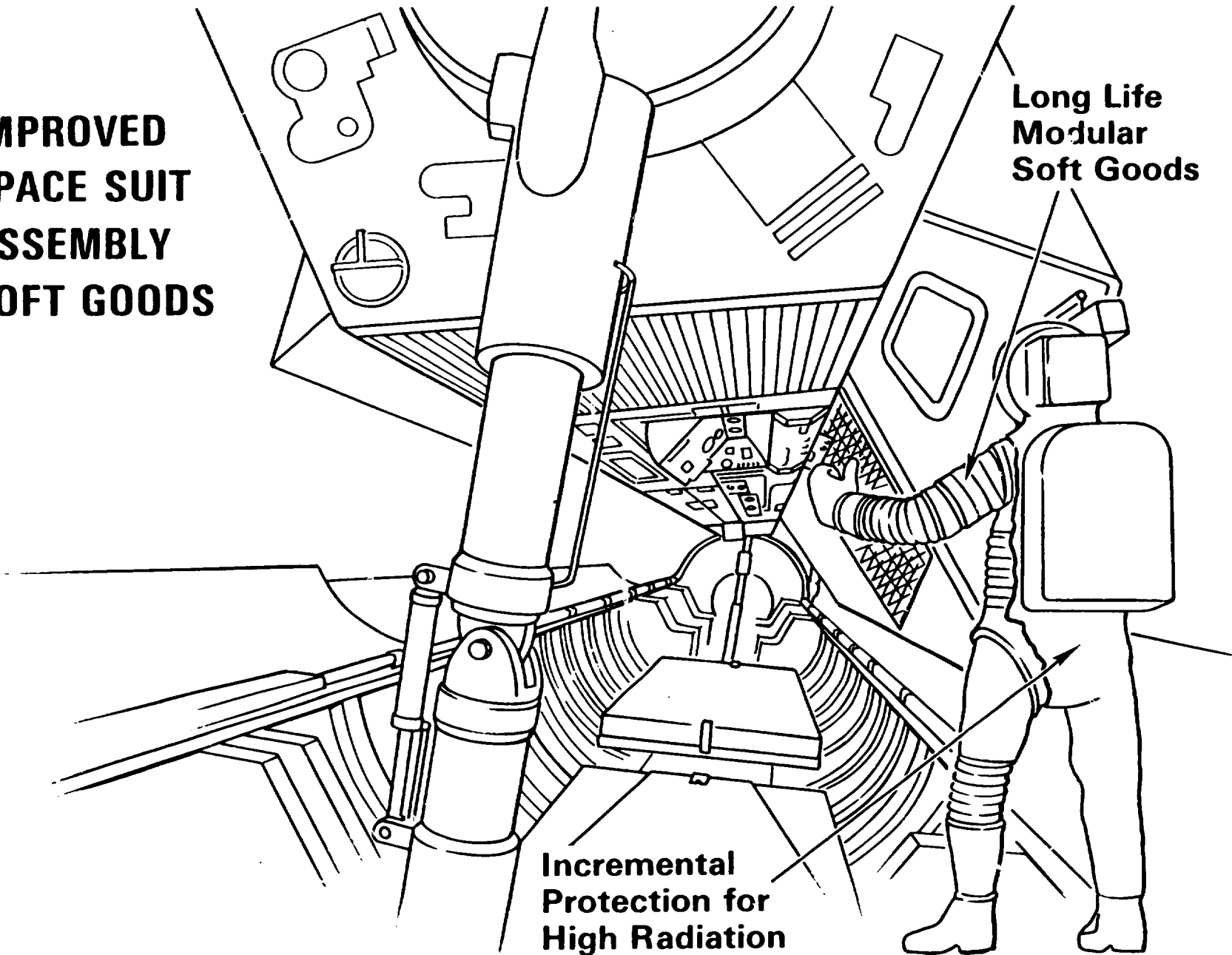
CAPABILITY PACKAGE NO. 5

1. Capability - Improve EMU Capability
  - Reduce dependence on vehicle-supplied consummables
  - Improve life of EVA softgoods
  - Increase EVA duration
2. Equipment - Package No. 4 plus:
  - Long life, modular SSA softgoods
  - Incremental hazards protection
  - Enhanced computer capability, including
    - Wrist display/control
    - Automatic temperature control
    - Plug-in diagnostic and service routines
  - 8 hour EVA capability
  - Regenerable CO<sub>2</sub> removal
  - Non-venting heat sink
3. Satellite Operations - Same as for packages 2, 3 and 4.
4. Satellite Subsystems - Same as for packages 2, 3 and 4.
5. Service Operation Location - Payload bay or within RMS reach envelope
6. Specific Service Tasks - Tasks of packages 2, 3 and 4 plus
  - Longer EVA capability
  - Reduced IV service time
  - Sequential display of service procedure steps

**IMPROVED  
SPACE SUIT  
ASSEMBLY  
SOFT GOODS**

**Long Life  
Modular  
Soft Goods**

**Incremental  
Protection for  
High Radiation  
Orbits**



## REQUIRED TECHNOLOGY DEVELOPMENT FOR CAPABILITY PACKAGE NO. 5

The following items of equipment listed for capability Package No. 5 will require technology development.

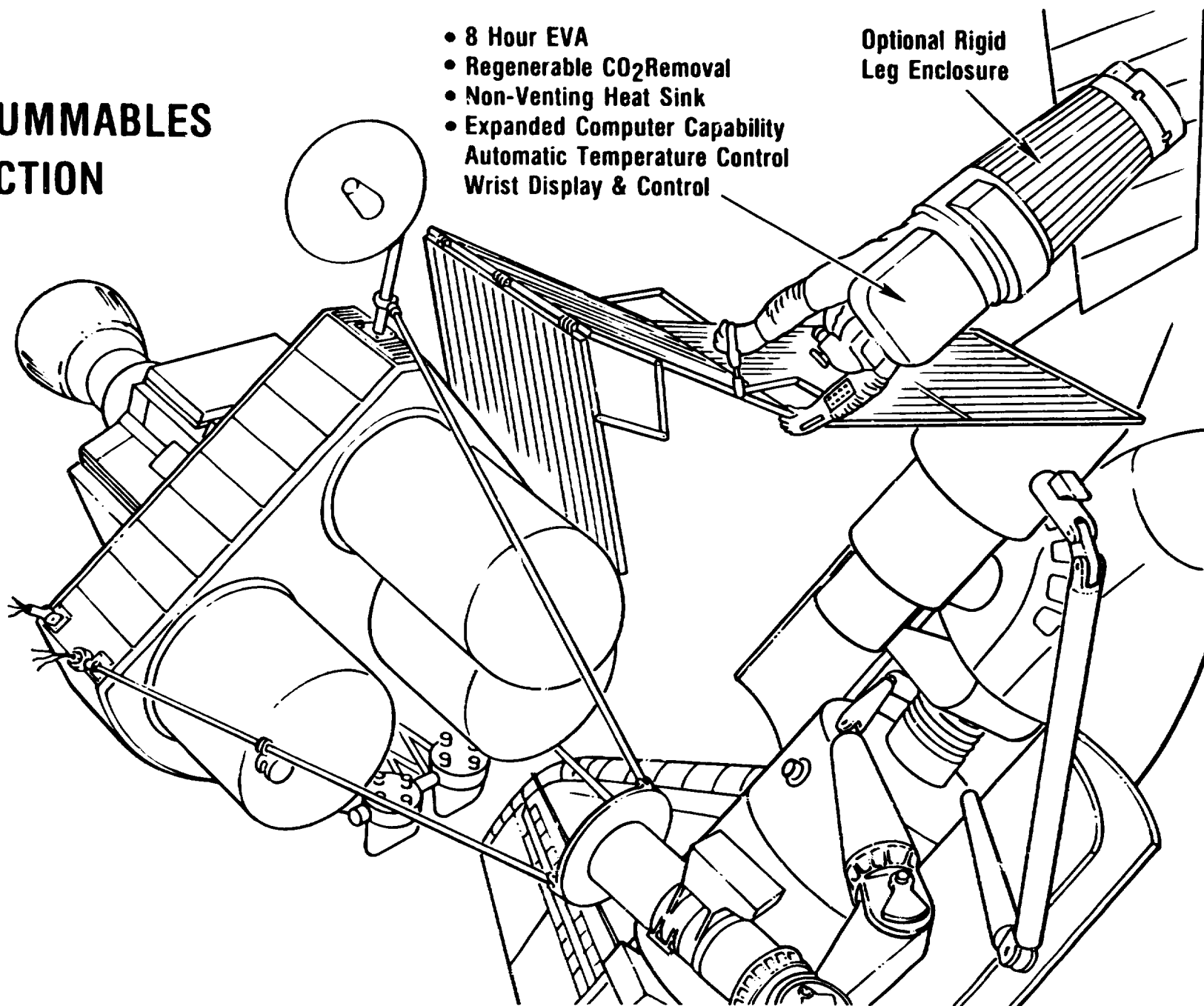
- Long-Life Modular Softgoods - An improved space suit assembly to support high levels of EVA and long mission durations.
- Incremental Hazards Protection - Workplace hazards protection tailorable to predicted radiation levels in different orbits.
- Enhanced Computer Capability - Expanded capability of the caution and warning computer to control LSS functions automatically and step the EVA crewmember through satellite service procedures.
- Regenerable CO<sub>2</sub> Removal - Non-expendable CO<sub>2</sub> removal to reduce EVA use of consummables.
- Non-Venting Heat Sink - Non-expendable heat rejection to reduce EVA use of consummables.



# EMU CONSUMMABLES REDUCTION

- 8 Hour EVA
- Regenerable CO<sub>2</sub> Removal
- Non-Venting Heat Sink
- Expanded Computer Capability
- Automatic Temperature Control
- Wrist Display & Control

Optional Rigid  
Leg Enclosure



## EVA PRESSURE ENCLOSURE DESIGN CONCEPT

The ECWS EVA enclosure design concept combines the best features of the Shuttle EMU SSA and the NASA advanced technology suits to meet the requirements of the ECWS missions. As such the ECWS enclosure represents the coming together of two suit evolutionary lines, namely, the "soft" suit traditions of Gemini, Apollo and Shuttle programs and the "hard" tradition of the advanced technology NASA suits. In their present forms, both of these suit lines are hybrids, containing both hard and soft elements. The ECWS EVA pressure enclosure concept further blends the two traditions in areas that serve the particular requirements of ECWS missions. The ECWS EVA pressure enclosure concept is described in Volume 2 of this report.

New technology is concerned with meeting 8 psi capability with 5,000,000 cycle life. The recommended approach is to combine joints, bearings, interjoint connectors and laminated wall fabric elements into modules for testing.

- Limb Joint Module Development

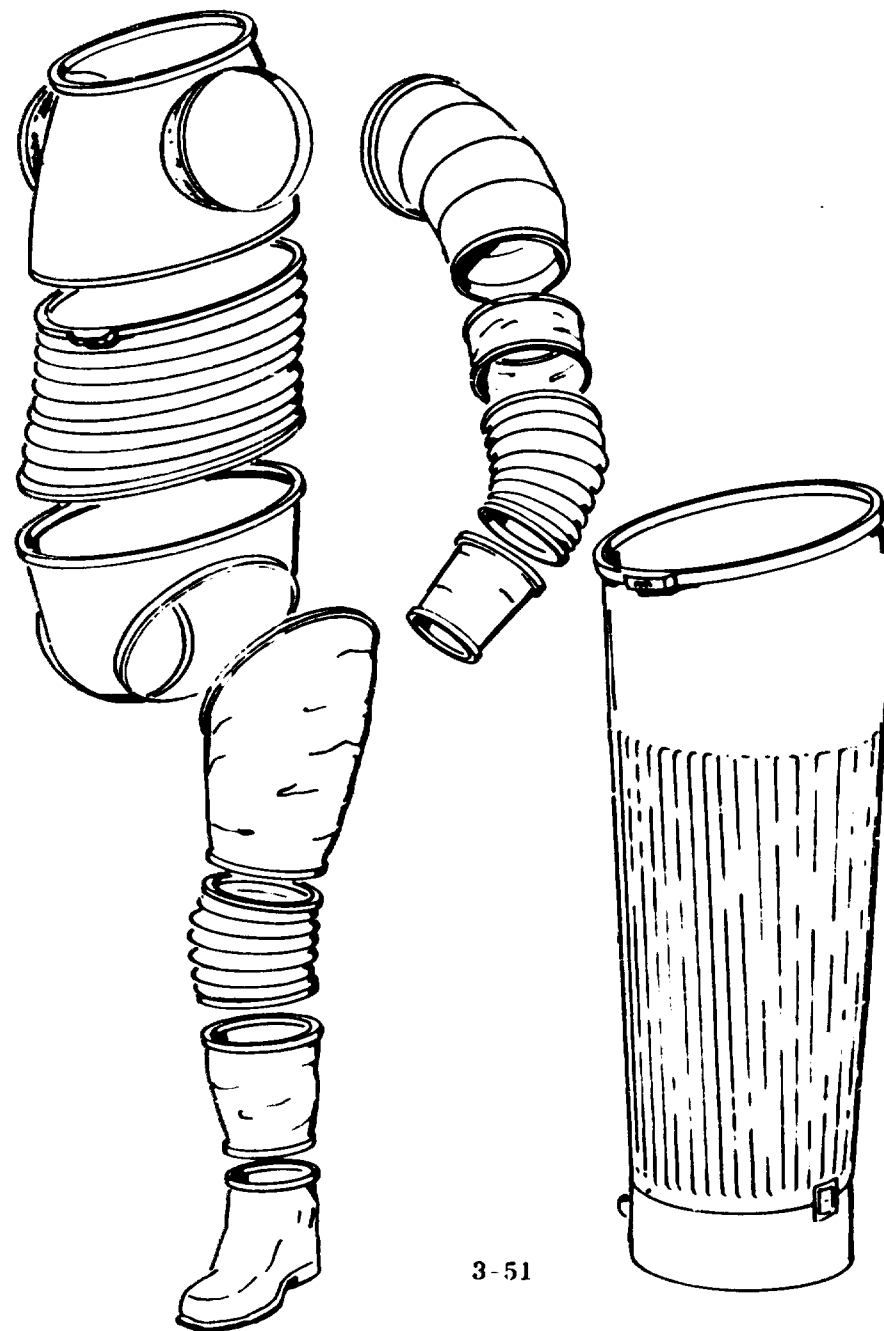
For 5,000,000 cycle life and potential 8 psia operation, torroidal joint modules and stovepipe joints represent the best approach for ECWS missions. The recommended development program consists of joint design to incorporate a laminated fabric wall, which integrates the bladder and restraint into one fabric structure, and uses a mechanical axial restraint linkage to withstand 8 psig plug loads. The joints then are to be cycled in manned testing for 5,000,000 cycles.

Duration: 24 Months

- Waist Joint Module

The waist, owing to its large diameter, appears to require an implementation that controls the fabric deformation geometry in order to achieve the requisite life. A likely implementation is the torroidal joint, which flexes without puckering and without severe material deformation. This avoids local stress concentrations and contributes to its long life and excellent flexibility. Hence, the torroidal joint is well suited for the waist joint as well as for other joints where 5,000,000 cycle life is sought. Torroidal joints are of molded construction, which is relatively expensive to manufacture. The technology program for this joint includes manufacturing cost reduction and demonstration of 8 psi operation for 5,000,000 flex cycles.

Duration: 12 Months



## EVA PRESSURE ENCLOSURE DESIGN CONCEPT (Continued)

### Shoulder Joints

Shoulder joints represent a singular requirement in that the desired, minimum-bulk joint design is tapered. The hard, stove pipe joint appears capable of meeting the 5,000,000 cycle life requirements, and in addition, can be made in a tapered configuration.

The recommended development program for the shoulder stovepipe joint consists of refining the design to minimize the motion-programming requirement, and to minimize the rotating friction between sections. In addition, impact resistance must also be considered in the design because of the potential for knocking the sections out-of-round, and thus restricting the relative rotations of adjacent joint sections. Lastly, 5,000,000 cycle life at 8 psig should be demonstrated with acceptable levels of torque and leakage.

Duration: 12 Months

### - Donning Ease

Donning ease is determined largely by entry closure design and torso-enclosure sizing. The present movable-scye-bearing, Shuttle EMU, single-plane closure appears capable of easy donning by a wide range of population sizes.

The recommended development program for ECWS EVA enclosure donning ease consists of refining the single plane closure design to minimize the number of torso sizes required, while retaining the inherent simplicity of the single plane closure. The areas to be developed include donnability by the projected size range of the crewman population, and taking into account the varying arm and shoulder mobility levels of the projected population. In addition, the ability for the closure to remain within leakage requirements over the required cycle life of the closure should be demonstrated.

Duration: 12 Months

## EVA PRESSURE ENCLOSURE DESIGN CONCEPT (Continued)

- Rigid Leg Encasement

Evaluate task performance and crew acceptability with the legs rigidly encased. Underwater testing is a potential means for performing this evaluation. Specific aspects to be evaluated are: ease of positioning the body for projected tasks, psychological factors associated with leg confinement, and ability to cope with emergency and unforeseen situations.  
Duration: 12 Months

- Prototype Evaluation

Design, fabricate and evaluate a prototype EVA enclosure, embodying the features developed above. The evaluation should center on assessing the prototype EVA enclosure for its intended function, and should thus include evaluation of the design requirements as well as the adequacy of the implementation. The prototype could be tested on earth in a chamber or underwater, or it could be tested as a Shuttle flight experiment. Incorporate all recommended changes in the flight design.  
Duration: 24 Months

## INCREMENTAL HAZARDS PROTECTION

Analysis in Volume 2 shows that the radiation shielding requirement varies by a factor of 20 over the range of potential construction orbits. This suggests that radiation shielding should be divorced from the pressure enclosure, which is the most expensive part of the EVA enclosure, and provided as separate radiation-protection overgarment modules, each tailored to the severity of the radiation of environment of a particular orbit. This concept eliminates pressurizing the insulation flexing additional inflated bulk. The concept is described in Volume 2 of this report.

The basic technology development areas center about developing flexible, radiation-protective overgarments and improving the analytical tools to predict radiation dose exposure and its effects. This is consistent with the NASA philosophy of "design to dose" in which total radiation protection will be designed to limit radiation exposure to pre-established dosage limits. Since the design of optimized overgarments depends on the availability of improved analytical tools, improvement of the analytical tools must precede the overgarment development.

- Environmental Models - Present environmental modeling is conservative in two respects, namely, the intensity of the high energy end of the electron spectrum model is believed to be excessive, and the spectral models used, AE-5 (inner zone, Solar Min.) and AE-7 Hi (outer zone), represent the period of maximum radiation intensity within the variation of the 11 year solar cycle. In reality the radiation intensity varies by a factor of 2 to 10 over the energy spectrum within the solar cycle. In addition, an environmental model of the projected 98° inclination polar LEO should be prepared, as this model presently does not exist. Further study is recommended to refine the energy spectra and intensity variations in all projected orbits.  
Duration: 12 Months
- Prediction of Radiation Dose Exposures - The following specific issues require resolution or further work in order to design optimized radiation protection.

#### INCREMENTAL HAZARDS PROTECTION (Continued)

- The McDonnell Douglas CAM computer program is the prime means, developed so far, to translate the environmental radiation into a radiation dose received by a crewman inside a radiation shield. This program currently requires a very large memory core in order to store in excess of 200,000 60-bit address locations. This requirement severely limits where this program can be run to a few, larger computer installations. CAM should be modified to reduce the memory core storage requirement to permit the program to be run in smaller computer facilities.
- CAM, in its present form, predicts point skin doses only. It does not account for the effects of underlying tissues to restrict eye, organ or red BFO exposure. In addition, CAM does not permit variation in size, posture or sex of the crewman, nor does it contain a variable space suit model, which would permit the modeling of various amounts of shielding around various parts of the body. A further deficiency in CAM is the presence of a straight line radiation penetration model. Replacement with a Monte Carlo model would represent the particle and X-ray scattering phenomena more accurately. This would also permit evaluation of the potential hazard from X-rays produced by electrons striking high atomic weight (Z) areas of adjacent structure, and impacting the EVA crewman by scattering. It is recommended that CAM be modified to incorporate the above changes. Thus modified, CAM would become much more useful for designing optimized radiation shielding configurations.
- After CAM has been improved, it should be used in conjunction with the improved environmental models to predict cabin dosages received in 28 1/2°, 55° and 98° LEO, over the entire range of cabin wall thickness anticipated. In addition, CAM should be used in conjunction with an improved GEO model to predict cabin and EVA enclosure doses that reflect the diurnal variation in radiation intensity which amounts to a factor of from 1.3 to 13, depending on energy level. This effort would permit more accurate modeling of the dosages received within the cabin.
- LEO dose exposure levels, expressed in REM, depend in part on the quality factor (QF) assigned to protons. Skylab dosimetry was based on a QF of from 1.5 to 1.6. ECWS is based on 1.4. CAM should be checked to ensure that it contains the latest QF value, and that value must represent a consensus within NASA and the scientific community.

Duration: 24 months

#### INCREMENTAL HAZARDS PROTECTION (Continued)

- Dosage Standards - The following specific issues have been identified as requiring resolution or further work in order to permit implementation of the "design-to-dose" philosophy.

The radiation exposure limits currently specified for ECWS are based upon 1970 standards established by the Radiobiological Advisory Panel of the Committee on Space Medicine for the Space Science Board of the National Academy of Science. These standards were put forth to establish acceptable risk levels for a population of astronauts and space scientists larger than Apollo concerned with space missions involving nuclear systems. The standards are based on a primary reference risk which corresponds to an added probability of radiation-induced neo-plasma, e.g., leukemia, over a period of about 20 years, that is equal to the natural probability for the specific population under consideration. These standards also state that under Federal Radiation Council philosophy, government agencies have the freedom to adopt higher or lower levels of risk for specific situations, providing adequate justification has been supplied. Under demanding circumstances use of a risk greater than the reference risk may be justified. Analysis to date indicates that to support levels of EVA contemplated, a GEO vehicle will require thick cabin walls, equivalent to roughly one-half inch of aluminum, which may impose an unacceptable penalty on these vehicles. Therefore, it is suggested that the NASA radiation exposure standards be restudied to determine if a higher risk is acceptable.

Disagreement exists with respect to establishing a dosage contingency to cover exposure to man-made radiation sources and unplanned exposure to natural radiation sources in orbit. The ECWS Study Program is currently using only 60% of the allowed dose for schedule exposure, leaving 40% contingency. This contingency should be reviewed from a vehicle design or mission planning point of view. This issue must be resolved by NASA in order to provide a firm dosage target against which both vehicle and EVA radiation shielding designs can proceed.

Duration: 8 Months

- Hardware Development

Hardware development must follow the refinement of the analytical tools and updating of the dosage standards in order to utilize the latest tools and dosage limits.



### INCREMENTAL HAZARDS PROTECTION (Continued)

- Cabin wall thicknesses, EVA durations and EVA frequencies must be defined as part of total radiation shielding definition, because the dosage received by the crew in the cabin, between EVA's, reduces the allowable dose they can receive during EVA. This is a significant trade study area, and should be performed prior to the detail design of EVA radiation shielding.
- Prototype design and development of radiation-protective overgarments is necessary to select the optimum materials and learn how to use them. Joint area flexibility and X-ray stoppage are particular areas requiring study. For example, electron irradiation of the EVA enclosure produces secondary X-rays as the electrons are slowed down. One concept for absorbing both X-rays and electrons is to decelerate the electrons with a low Z shield, thus producing relatively soft X-rays. The X-rays would then be blocked with a thin inner layer of high Z shielding material. This approach may be lighter or easier to implement than providing a homogeneous one-Z shield to stop both the electrons and X-rays. A completed garment sample should be tested for radiation protection. One concept for testing consists of instrumenting an anthropomorphic dummy with dosimeters, clothing it in the combined THRO and ECWS pressure enclosure, and exposing it to space radiation by using the projected Long Duration Exposure Facility (LDEF).  
Duration: 18 Months

- Real Time Dosimetry - To facilitate real time mission planning it is very important to be able to assess accumulated radiation dosages in flight, and not have to return to earth to make this assessment. This is particularly significant in planning emergency EVA or in considering a mission abort following an unplanned exposure. Therefore, it is recommended that the on-going work continue to bring in-flight, real time dosimetry to flight status.

- Flare Detection

Flares, or Solar Particle Events (SPE) represent a real hazard to both EVA and IVA crews at LEO orbits with inclination greater than 28 1/2° as well as to GEO crews. Reliable SPE warning is required to permit crews to take evasive action.

Duration: 24 Months

## ENHANCED COMPUTER CAPABILITY

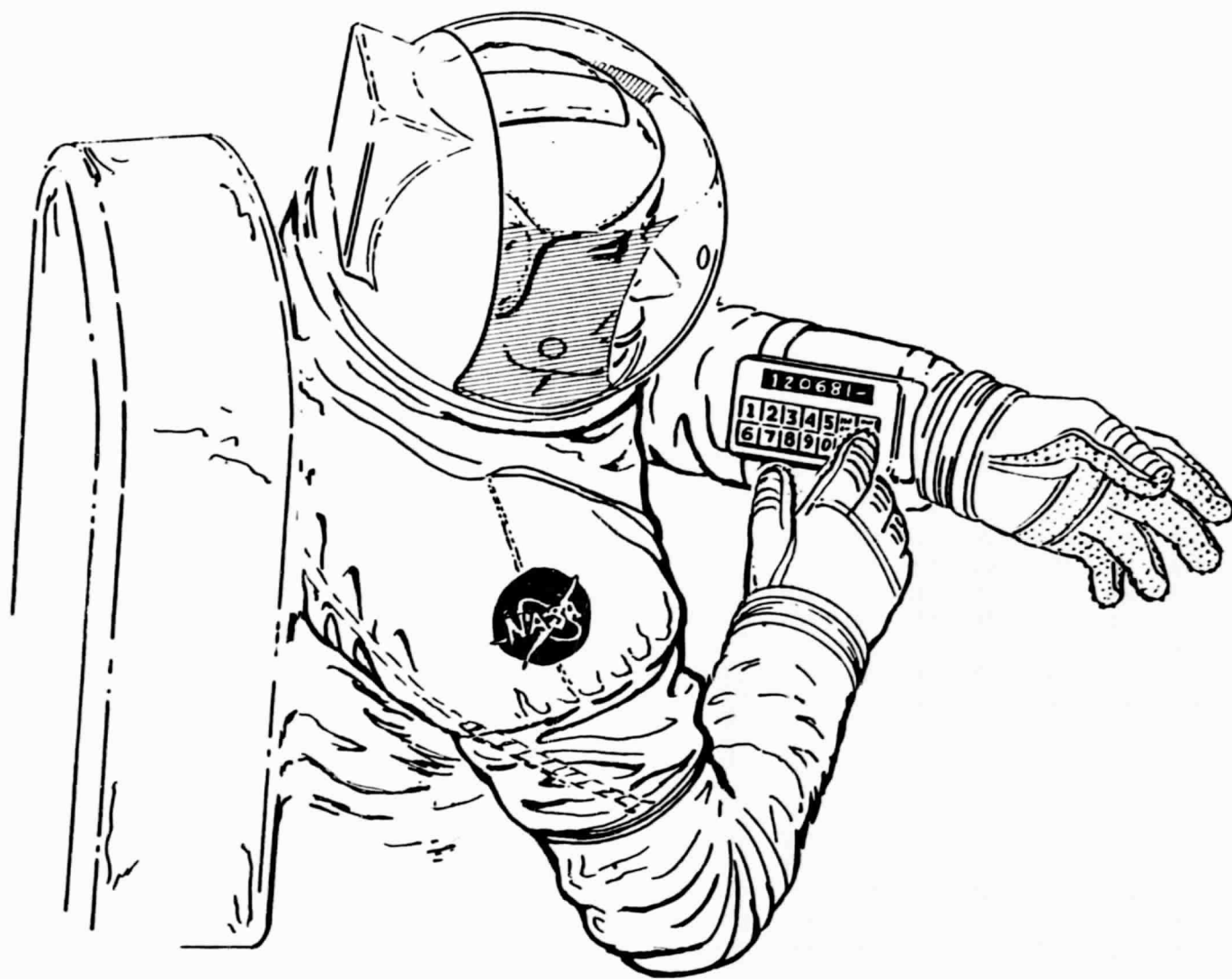
Advances in microprocessors and fiber optics offer the potential for eliminating the chest-mounted DCM, and replacing it with a much smaller wrist-mounted keyboard and display. The key to this concept is to use the microprocessor to control the LSS, with the crewmember inputting commands via the keyboard. The display generates readouts using information generated by the microprocessor, and transmitted either via electrical or optical lines to the readout.

In addition the caution and warning system computer capability can be increased to provide additional EVA support capability. It is recommended that some capabilities be implemented with capability package No. 5, and that others be phased in as part of capability package No. 7.

Capabilities recommended for implementation in capability package No. 5 are automatic temperature control, described in Volume 2 of this report, and plug-in diagnostic and service routines, described in Volume 3.

Technology development for enhanced computer capability centers around software definition. A study to identify software needs for capability package Nos. 5 and 7 is recommended prior to freezing memory size or system architecture.

Duration: 12 Months



## REGENERABLE CO<sub>2</sub> REMOVAL

The concept consists of the K<sub>2</sub>CO<sub>3</sub> transport loop, an absorber, desorber, pump, accumulator and back pressure regulator. A liquid solution of potassium carbonate (K<sub>2</sub>CO<sub>3</sub>) enters the absorber unit. Metabolically produced CO<sub>2</sub> and water also enter the absorber via the vent gas stream. A membrane separates the gas and liquid flow streams. The membrane also permits CO<sub>2</sub> to diffuse from the vent flow streams into the liquid stream. The CO<sub>2</sub> and water are reacted by the following equation:



The solution is then pumped to the desorber unit which also uses a membrane. The low pressure reverses the reaction, rejecting the CO<sub>2</sub> to vacuum along with some water vapor. The evaporation of water cools the liquid flow stream. While the system relies on water loss to operate, the amount of water lost is more than offset by the metabolic condensate produced over the range of 400 to 2000 Btu/hr. It is expected that the water loss incurred by the K<sub>2</sub>CO<sub>3</sub> process will serve to reduce the condensate storage requirement of the ECWS LSS. A pressure regulator controls the gas pressure outside the membrane to a low enough level to permit CO<sub>2</sub> diffusion, but high enough to prevent freezing and to limit evaporating of water.

New technology is required to develop membranes. Ideally a membrane can be found which does not impede the diffusion of CO<sub>2</sub>. Hence, the thrust of the new technology program centers on the membrane selection and testing, which in turn, drives the follow-on activities.

- Membrane Search - Find or develop a suitable membrane which allows the liquid sorbent to operate at full capacity, and still limits water loss. Test candidate membrane types, varying pore size and degree of hydrophobicity. Success or failure of this initial, short term effort will determine if the liquid sorbent concept is feasible or not. Therefore, new technology planning should include a go/no-go evaluation and a repeat of the subsystem trade study at the end of this phase.  
Duration: 12 Months
- Solution Properties - Verify the theoretical solution properties at the conditions of temperature, pressure and CO<sub>2</sub> partial pressure under consideration by test. Determine if catalysts should be used, and if so, which ones.  
Duration: 12 Months
- Prototype - Design and build a prototype system to provide the practical background to size both sorber elements, define optimum liquid flow rate and establish the gas (O<sub>2</sub> and H<sub>2</sub>O) losses.  
Duration: 24 Months

### NON-VENTING HEAT SINK

The non-venting heat sink consists of a 4 hour phase-change material coupled to a detachable radiator. The features of the concept are:

- A three-fluid heat exchanger in the LSS cools the LCVG flow and vent flow with chilled fluid. A slurper on the vent flow outlet from the heat exchanger draws off condensate.
- A 4-hour, refreezable, ice heat sink cools the fluid in the three-fluid heat exchanger. As the melting occurs at constant temperature, the circulating chilled fluid is at constant temperature. The only moving part is the pump which circulates liquid from the PCM to the heat exchanger. The PCM is refreezable between EVAs. It is separate from the LSS liquid loop to permit refreezing without breaking the LSS liquid lines in flight.

Adding the radiator building block eliminates the need for using any expendable vehicle water. The 15 ft<sup>2</sup> radiator would be added to the LSS during EVA. It can be left at the worksite, permitting the crewman to use the PCM during transit between the airlock and worksite. During periods of low solar influx the radiator will tend to refreeze the PCM. It, too, can be added and removed without breaking the LSS liquid loop.

The non-venting heat sink concept is a new combination of technologies that have already been proven separately in the laboratory, but which have not yet been integrated or proven in flight. Therefore, the technology development program emphasizes a prototype build-and-test approach to demonstrate the compatibility of the refreezable heat sink with the radiator. Other specific areas to be investigated are:

- Improve the packaging efficiency of the refreezable heat sink.
- Develop the ability to vent the PCM heat sink, LSS heat exchanger and radiator of radiator fluid prior to bringing these units into the cabin for repair or maintenance, and to refill them with radiator fluid prior to returning them to service. Conceivably all venting and filling could be performed in the depressurized air lock.
- Conduct performance testing in a large, earthbased vacuum chamber or as a Shuttle flight experiment. Identify changes required in flight hardware design.

Duration: 24 Months

### NON-VENTING HEAT SINK (Continued)

Addition of the radiator completes the non-venting heat sink concept. Specific aspects of the radiator are best handled in a prototype build-and-test program, designed to supplement the prototype development of the PCM heat sink concept. Other specific areas to be investigated include:

- Demonstrate radiator - PCM heat sink compatibility and the ability to operate the system with and without the radiator.
- Demonstrate the ability to make and break the radiator line disconnects safely and reliably in vacuum.
- Design the control system that functions with the radiator and PCM heat sink.
- Demonstrate radiator design aspects of folding and anchoring to the LSS structure or workstand.

Duration: 24 Months

- Conduct performance testing either on Earth or as a space flight experiment.  
Demonstrate ability to withstand long periods of disuse in space without ill effects.

Duration: 12 Months

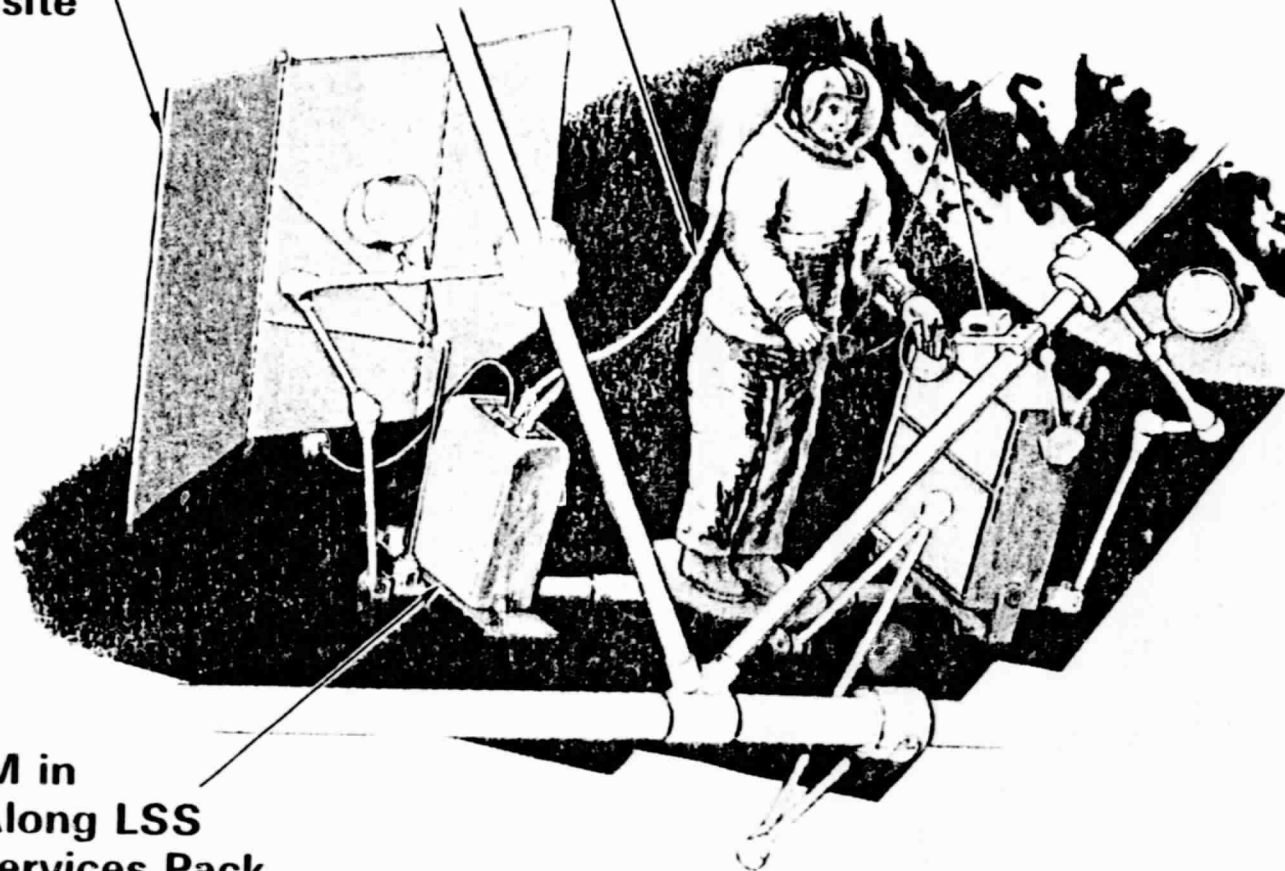
## GENERAL ARRANGEMENT OF NON-VENTING HEAT SINK

Deployed LSS Radiator  
Attached  
to Worksite

25 Ft  
Umbilical

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Ice PCM in  
Carry-Along LSS  
Basic Services Pack

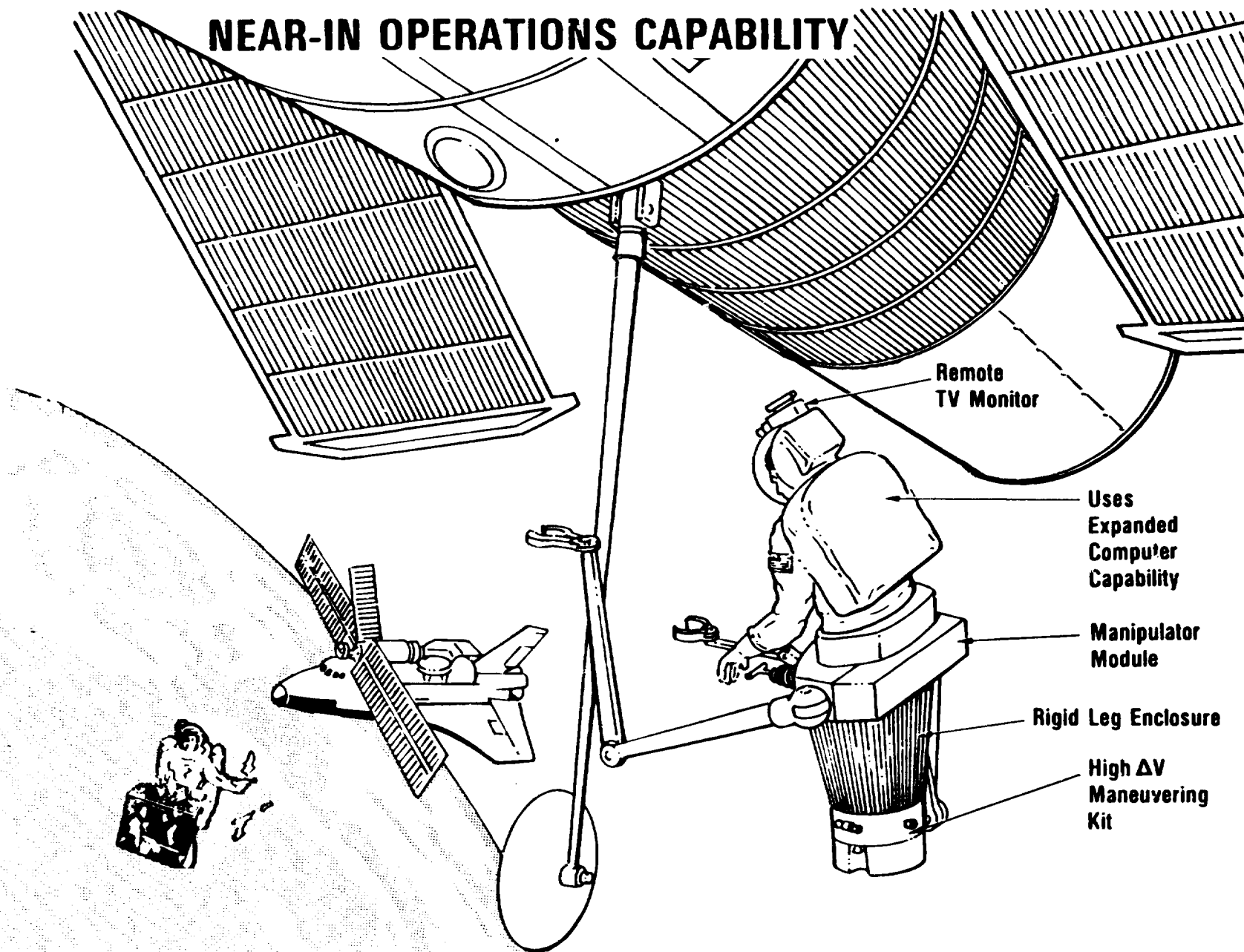


## CAPABILITY PACKAGE NO. 6

1. Capability - Develop Near-in EVA Capability .
2. Equipment - Package No. 5 plus:
  - Satellite Services MMU
  - Rigid Leg Encasement w/radiator
  - Remote TV Monitor
  - Remote Service Kit
  - Manipulator Module
3. Satellite Operation - Near-in inspection, safetying, and service
4. Satellite Subsystems - Same as for Packages 2, 3 and 4
5. Service Operation Location - Within 100 m of Orbiter
6. Specific Service Tasks - Tasks of Packages 2, 3 and 4 plus:
  - Free flying assistance with docking, berthing and snaring
  - Remote inspection, safetying, subsystem diagnosis and service.



## NEAR-IN OPERATIONS CAPABILITY



#### REQUIRED TECHNOLOGY DEVELOPMENT FOR CAPABILITY PACKAGE NO. 6

The following items of equipment listed for capability package No. 6 will require new technology development.

- Satellite Service MMU - A high  $\Delta V$  maneuvering unit to support EVA away from the Orbiter.
- Rigid Leg Encasement With Radiator - Integrated leg enclosure and radiator to support free-flying EVA sorties.
- Remote TV Monitor - A portable TV camera mounted to the EVA crewmember, and under control of the IV crew in the Orbiter.
- Manipulator Module - An optional EVA equipment module to provide a stronger grip or longer reach than human hands and arms can provide.

## SATELLITE SERVICE MMU

Satellite service MMU is a personal propulsion system with increased  $\Delta V$  and quick recharge capability. One version, similar to the present MMU, is described in Volume 3 of this report. It is intended to be compatible with an SSA with legs.

An alternative concept is to integrate MMU functions with the rigid leg encasement, adding thrusters to the shoulder area as well. This concept is described in Volume 2 of this report.

Technology development centers around choice of propellant for the increased  $\Delta V$  capability. A study is recommended to determine  $\Delta V$  requirements for satellite service tasks of capability package Nos. 6 and 7; and to recurrent propellant choices.

Duration: 6 Months

A prototype development program is recommended to identify and resolve interface problems prior to starting final design. This will be especially valuable for an MMU concept that is integrated with the ECWS.

Duration: 24 Months

### INTEGRATED LEG ENCLOSURE AND RADIATOR

Integrating the leg enclosure and radiator results in a compact, low bulk package well suited for free-flying EVA. A mock-up and prototype evaluation is recommended to identify and resolve interface problems prior to starting the flight hardware design.

Duration: 12 Months

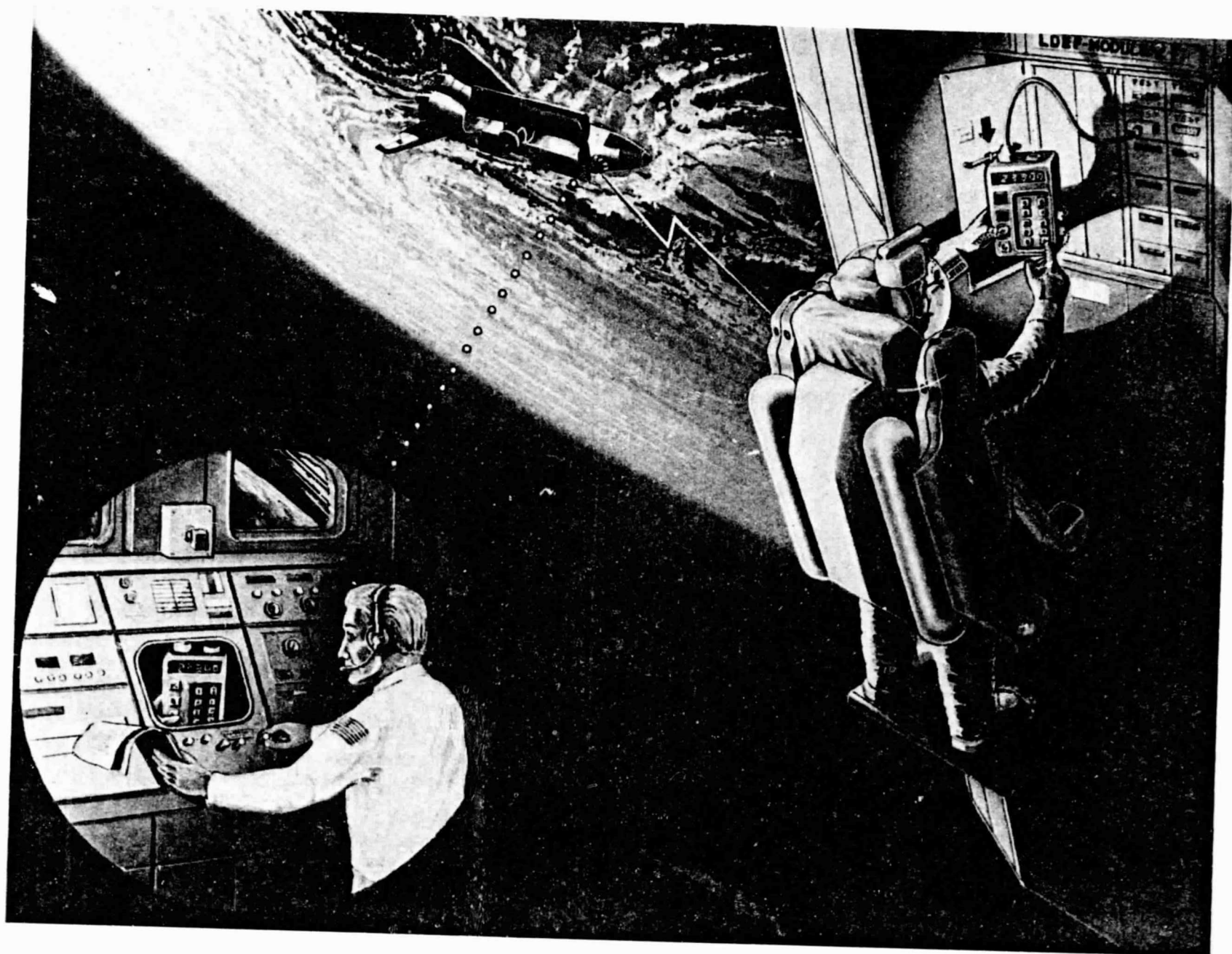
## REMOTE TV MONITOR

Remote TV permits IV crewmembers to support EVA tasks. The concept, described in Volume 3 of this report, consists of a helmet-mounted TV monitor under control of the IV crew. Focus, azimuth and elevation can be controlled to provide the IV crew with the desired view.

Technology development centers on packaging and integration. Minimum volume is highly desirable, hence a packaging and integration study should seek to use state of the art technology to minimize bulk. In addition requirements should be carefully assessed. Requirements to be defined include low light capability, minimum image resolution, black and white or color imaging, and range of focusing, altitude and azimuth swing. The requirements definition study should be followed by a preliminary design and mockup evaluation.

Duration: 18 Months

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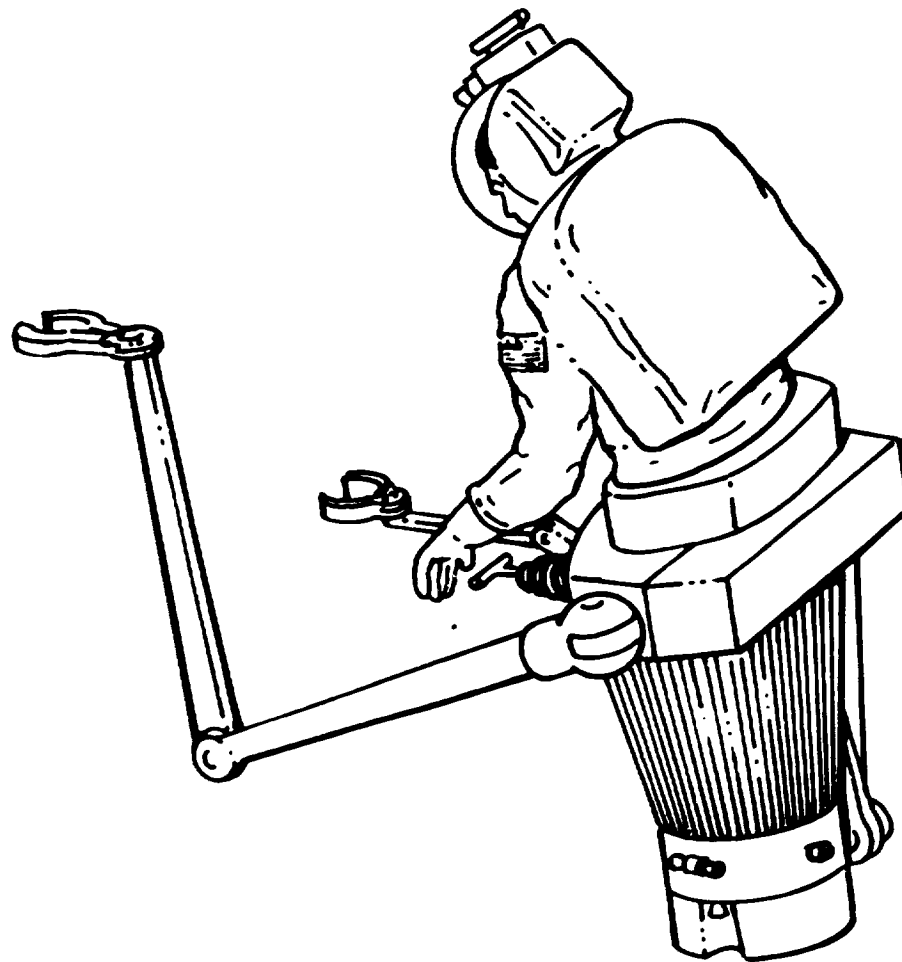
### MANIPULATOR MODULE

The manipulator module concept, described in Volume 2 of this report, is an optional capability to be used for tasks requiring a longer reach or stronger grip than human arms and hands can provide.

As with the TV monitor concept, technology development centers on requirements for packaging and integration. Minimum bulk is desirable. Because reach, strength and dexterity affect bulk, requirements must be carefully defined at the outset. Hence a requirements definition study is recommended, to be followed by preliminary design, mockup evaluation, and a functional prototype.

Duration: 24 Months

## INTEGRATED ECWS AND OPTIONAL MANIPULATOR MODULE





## CAPABILITY PACKAGE NO. 7

1. Capability - Service up to 10 km from Orbiter
2. Equipment - Package No. 6 plus:
  - Rate - Range - Spin Detector
  - Voice control of maneuvering unit
  - Transfer trajectory orbital mechanics
  - Heads up data display
  - Remote surface temperature sensing
  - Satellite stabilization kit
  - Satellite retrieval kit
  - Debris collection kit
3. Satellite Operation - Stabilize and retrieve out-of-control satellites free-flying collection of debris
4. Satellite Subsystems - All subsystems
5. Service Operation Location - Up to 10 km from Orbiter
6. Specific Service Tasks - Tasks of Package No. 6 plus:
  - Stabilize tumbling, out-of-control satellites
  - Retrieve unpowered satellite
  - Retrieve free-flying debris

## REQUIRED TECHNOLOGY DEVELOPMENT FOR CAPABILITY PACKAGE NO. 7

The following items of equipment listed for capability package No. 7 will require new technology development.

- Implementation of Enhanced Computer Capability - The expanded caution and warning system computer capability, provided in capability package No. 5, is developed to support EVA operations up to 10 km from the Orbiter. The enhanced computer capability provides:
  - Remote surface temperature servicing
  - Voice control of maneuvering unit
  - Heads up data display
  - Transfer trajectory orbital mechanics
  - Range - range rate - spin detection
- Satellite Stabilization Kit - Means for direct EVA stabilization of an out-of-control satellite.
- Satellite Retrieval Kit - Means for bringing a stabilized but unpowered satellite to within the Orbiter RMS reach envelope.
- Debris Collection Kit - Means for EVA retrieval of large and small pieces of space debris.

### IMPLEMENTATION OF ENHANCED COMPUTER CAPABILITY

Providing additional computer capability was recommended for capability package No. 5. Using the additional capability requires both hardware and software development to bring voice control of maneuvering system, heads-up data display, and remote surface temperature sensing to flight status. Basic technology development is not required, because general operating principles have been demonstrated. However, requirements definition and prototype evaluation are recommended to insure that the least-bulky systems capable of meeting requirements are developed.

Duration: 24 Months

There are several potential methods for implementing range-rate-spin and transfer trajectory orbital mechanics. These methods include doppler radar and laser ranging. A study step to select the best method is required, and should be implemented between requirements definition and prototyping phases. Except for this extra step, developing these capabilities uses the same process as voice control, heads-up display and remote temperature sensing discussed above.

Duration: 30 Months

## SATELLITE STABILIZATION KIT

The concept for satellite stabilization, presented in Volume 3 of this report, illustrates a potential approach for stabilization by direct EVA. Studies have shown that a large satellite such as the Space Telescope may be approached and stabilized by an EVA crewmember climbing aboard and using the MMU to despin the satellite directly. However, other significant issues such as safety, cost-effectiveness and imparting unwanted motions to the satellite must be identified and addressed.

A study is recommended to identify the issues involved in satellite stabilization, identify feasible methods for stabilization and define limitations of the methods. Recommendations should be made for methods to be developed.

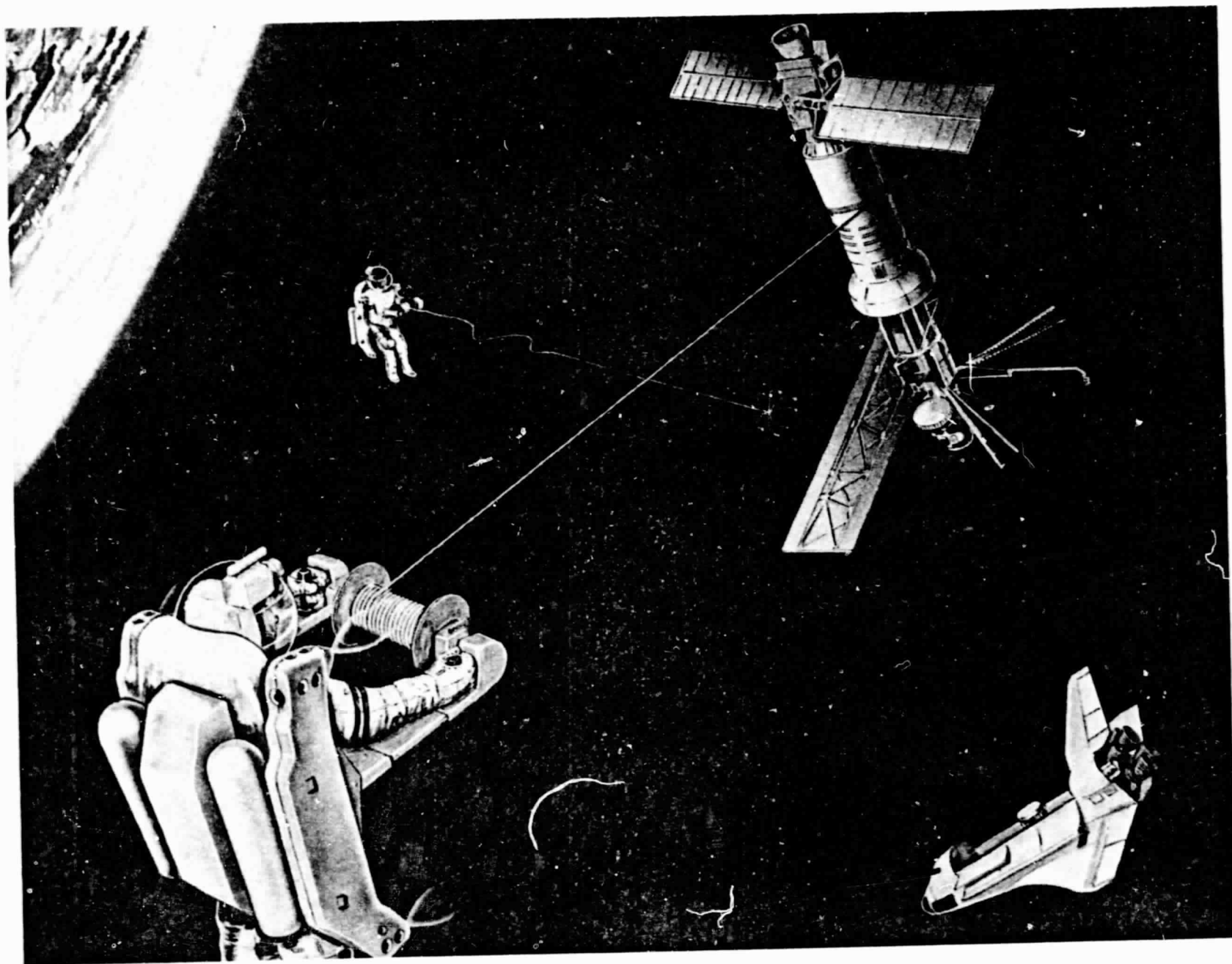
Duration: 12 Months

Prototype evaluation is recommended to demonstrate practicality of recommended stabilization methods. Initial demonstration could be performed in two dimensions, using the NASA JSC air bearing floor facility. Later a flight demonstration could be performed using a suitable, non-operational satellite.

Duration: 24 Months

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## SATELLITE RETRIEVAL KIT

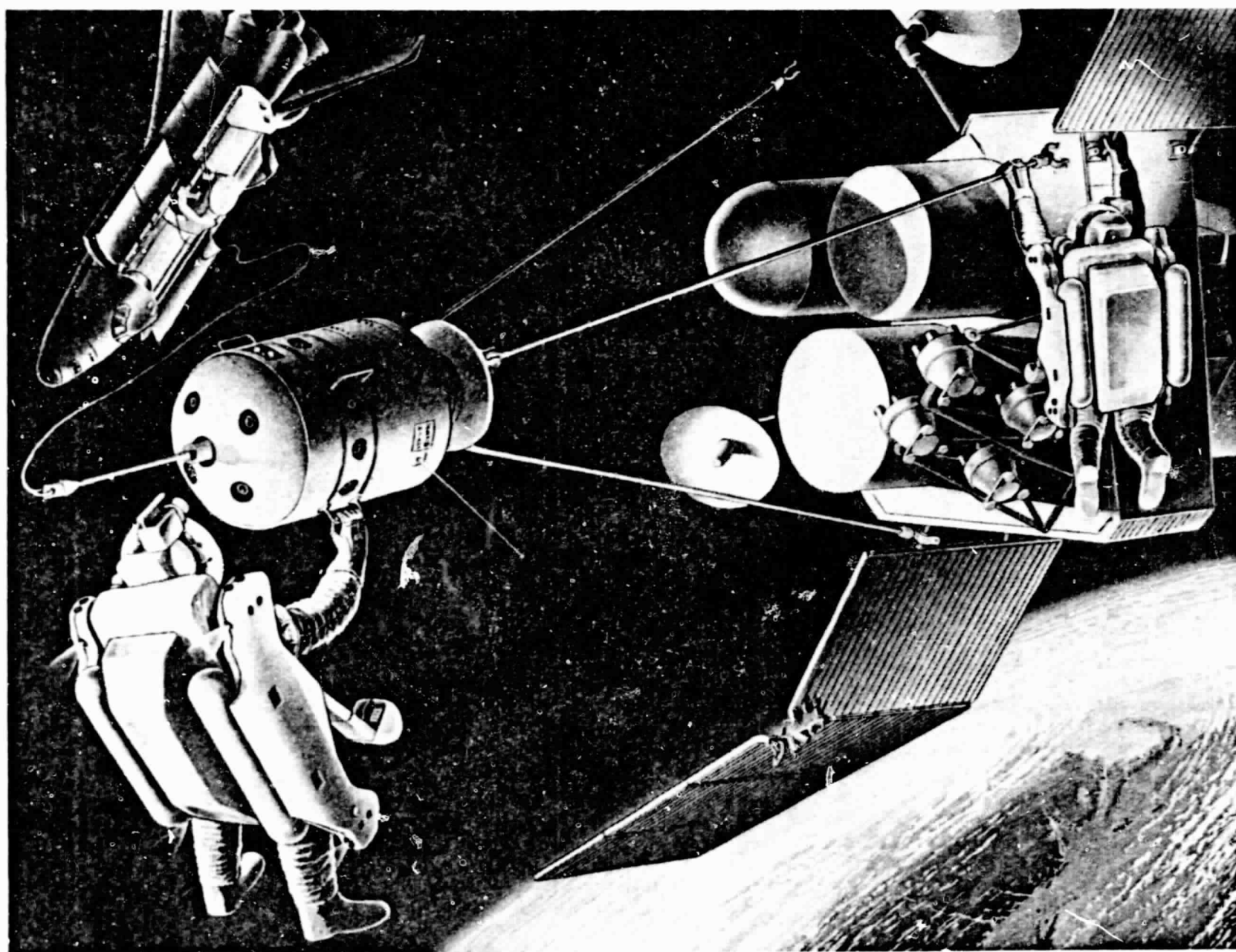
The concept for satellite retrieval, presented in Volume 3 of this report, illustrates a potential approach for satellite retrieval using EVA. Other satellite retrieval concepts include remote and EVA-controlled teleoperators.

A study is recommended to identify, evaluate and select recommended approaches to satellite retrieval. The study should consider the projected satellite population, EVA capability and the level of control technology expected to be available.

Duration: 8 Months

Prototype evaluation is recommended to demonstrate the practicality of recommended retrieval methods. Initial demonstrations could be performed in two dimensions using the NASA/JSC air bearing floor facility. Later a flight demonstration could be performed using a suitable, non-operational satellite.

Duration: 18 Months



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## DEBRIS COLLECTION

Collection of free-flying space debris poses several problems not expected to be encountered in other aspects of satellite service. These include orbital parameters not precisely defined, random sizes and shapes of objects and potentially sharp and jagged edges. Capturing these fragments and returning them to the Orbiter for return to Earth may be accomplished several ways. Capture by free-flying EVA, as described in Volume 3, is one potential approach.

A study is recommended in which the projected debris population is identified and candidate collection means identified, evaluated and selected.

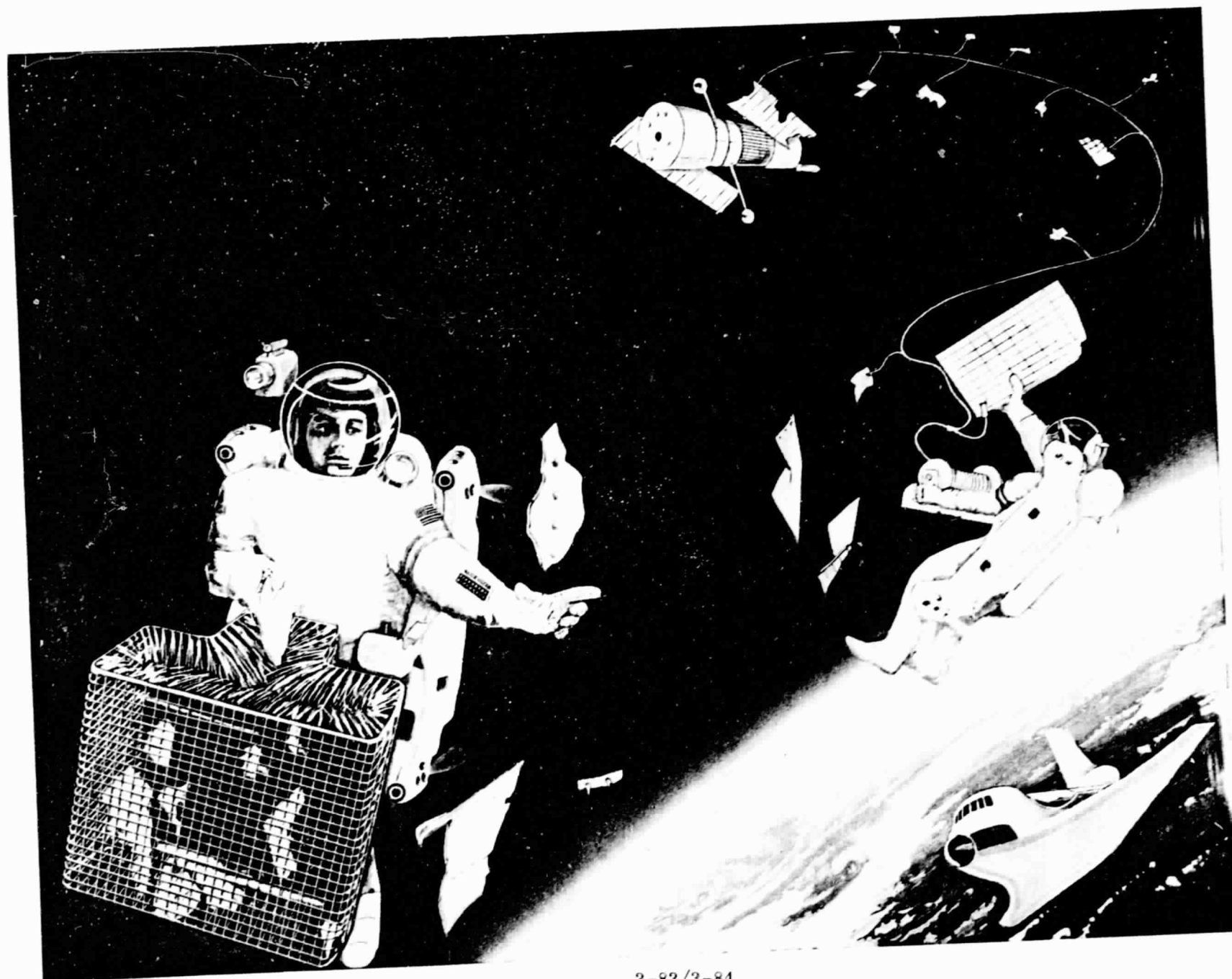
Duration: 6 Months

A prototype debris collection system is recommended for flight evaluation.

Duration: 18 Months



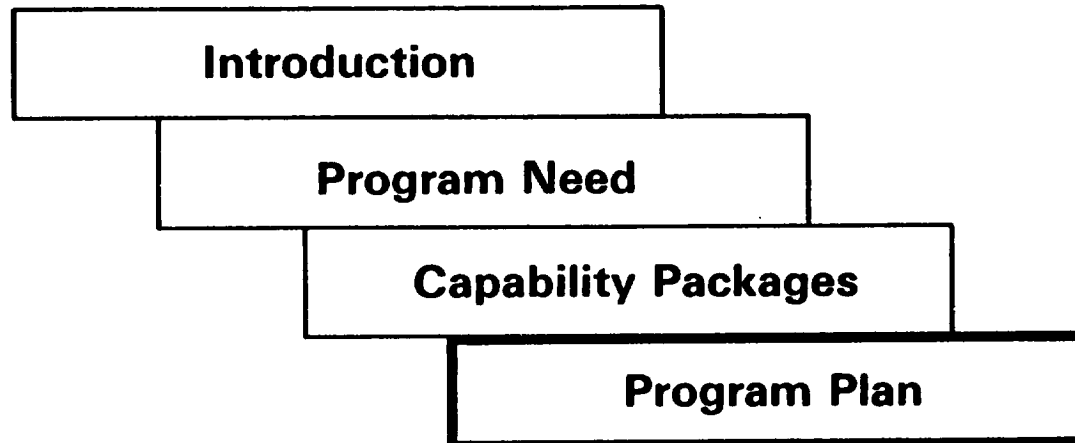
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# **EXTRAVEHICULAR CREWMAN WORK SYSTEM STUDY PROGRAM**

## **Final Report, Volume 4, Program Evolution**

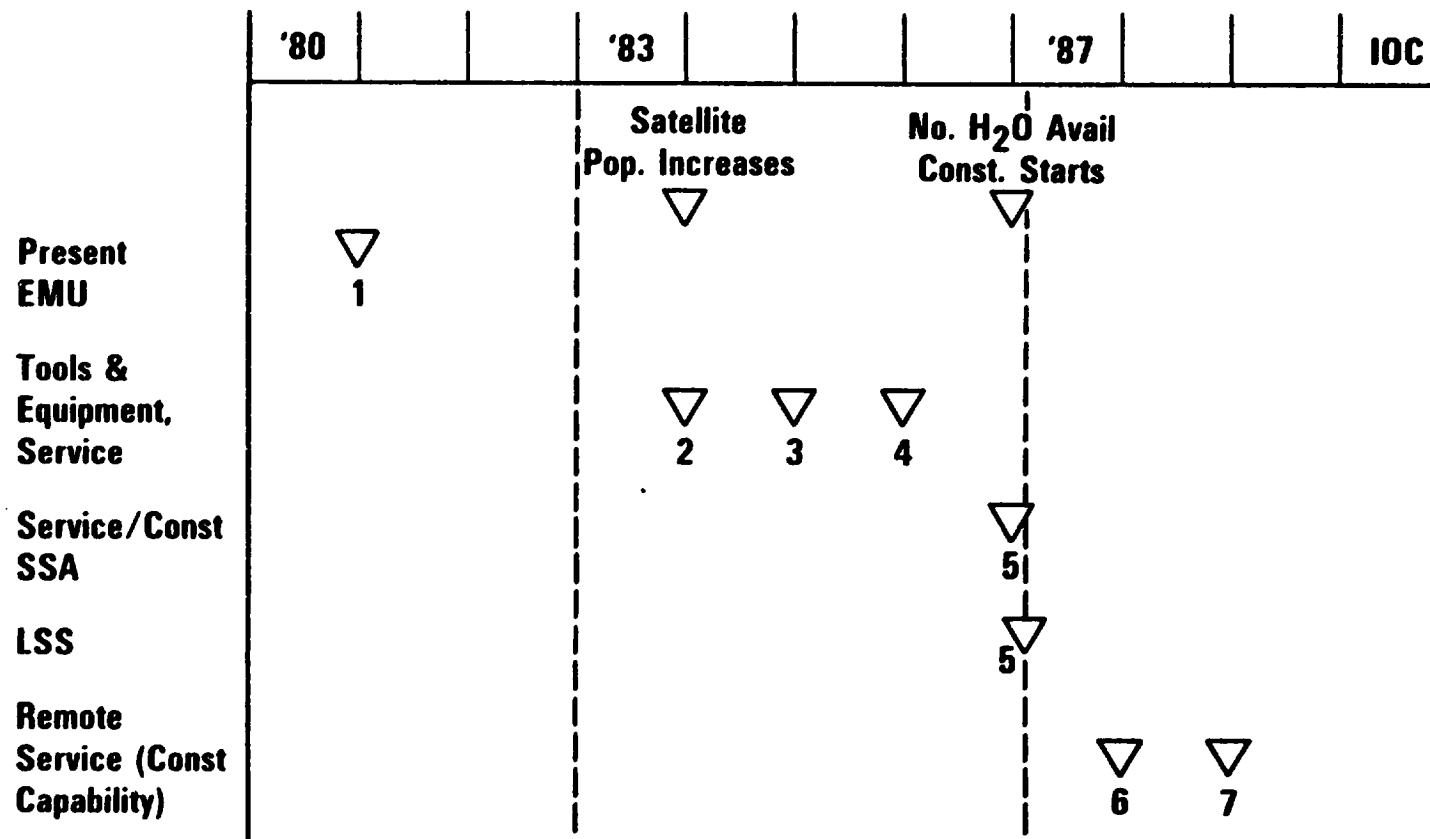


## EVA CAPABILITY EVOLUTION PROGRAM PLAN

Hardware procurement for EVA capability evaluation will require the following program steps in general:

- Concept
  - Identify requirements
  - Identify concepts
  - Evaluate and select concept
  - Develop technology to support design of selected concept
  - Manufacture and evaluate prototype
- DDT&E
  - Design
  - Develop - Hardware, software, interfaces, procedures
  - Test
  - Evaluate - WIF, Test Chamber, K-Bird, Flight
- Manufacture
  - Fabricate
  - Assemble
  - Acceptance Test
  - Integration into STS operations
- IOC

# PROJECTED EVA CAPABILITY PACKAGE IOC SCHEDULE



1-7 = Capability Pkg's, ECWS Vol. 2  
SSA & LSS Defined Per ECWS Vol. 1

## EVA CAPABILITY EVOLUTION PROGRAM PLAN (Continued)

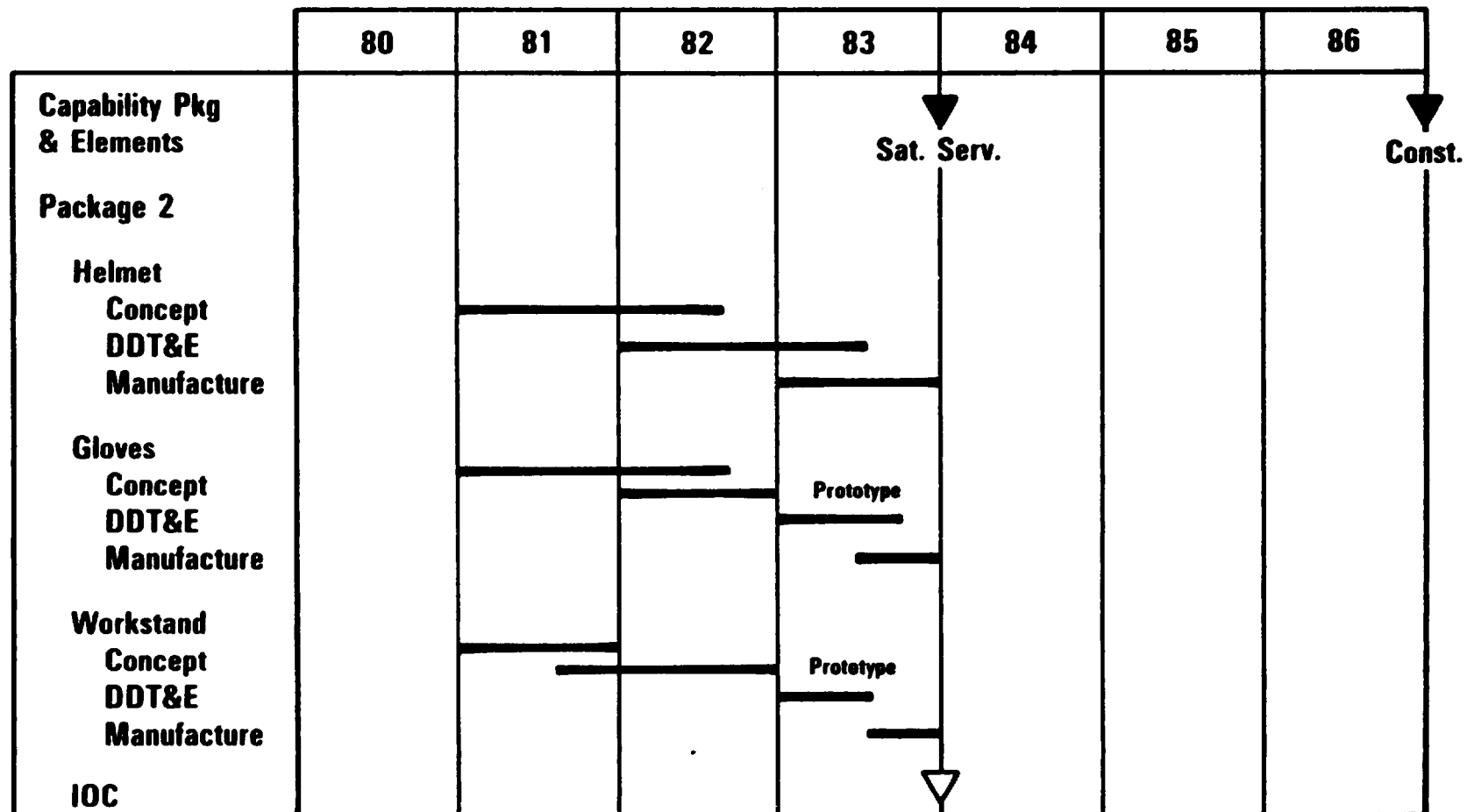
Lead times to procure major equipment items of each capability package were estimated. Elements contributing to lead times were selected from the above list. Lead times for each package were developed to meet the projected EVA capability need schedule on the accompanying page. The results, laid out on the following pages, represent the overall procurement schedules for the major equipment items of the EVA capability packages.

NOTE: DDT&E = Design, development, test and evaluation.

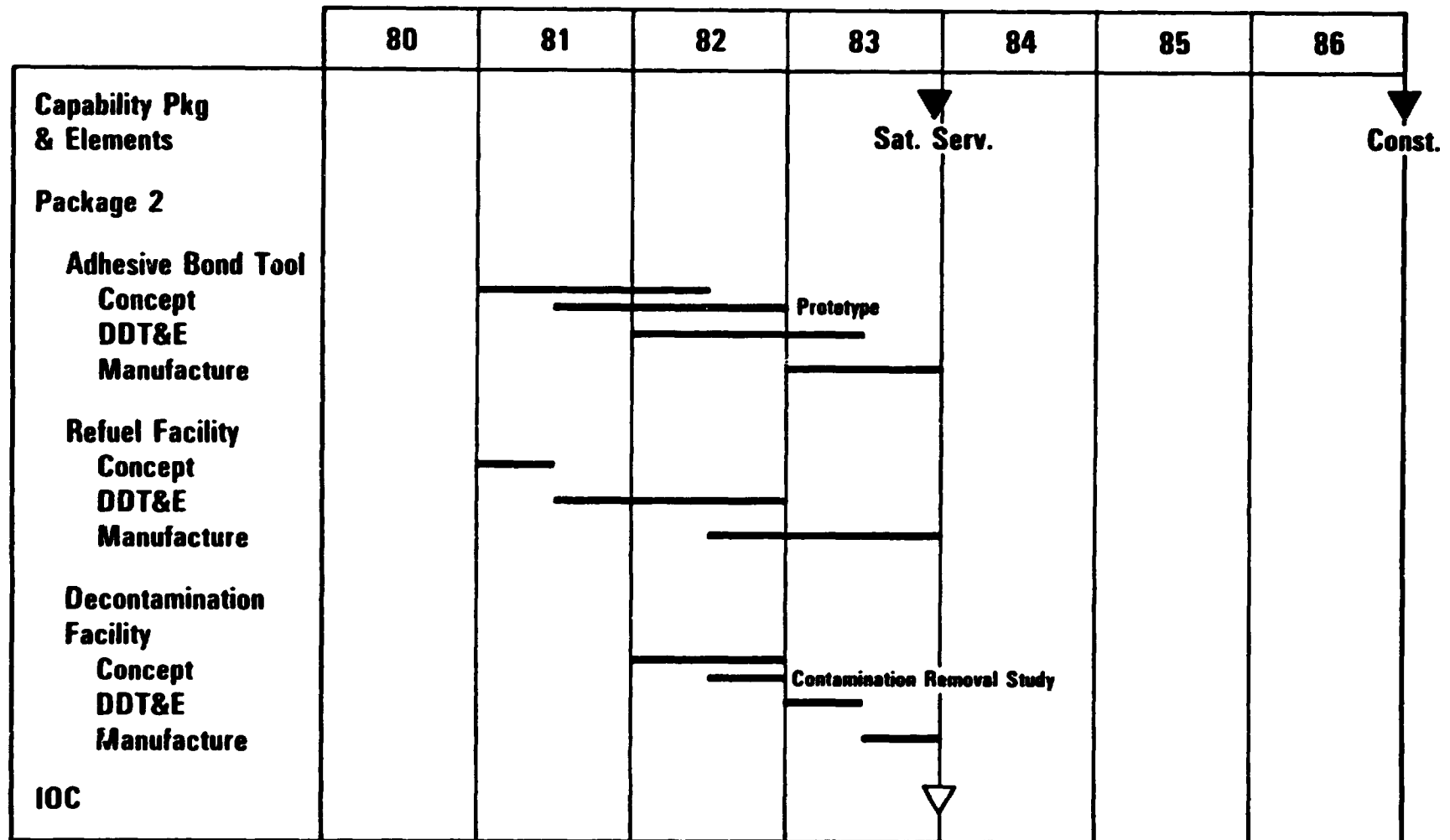
## DEVELOPMENT SCHEDULE FOR EVA CAPABILITY PACKAGE NO. 1

	80	81	82	83	84	85	86
<b>Capability Pkg &amp; Elements</b>				▼ Sat. Serv.			▼ Const.
<b>Package 1</b>							
<b>EMU, MMU RMS</b>							
<b>DDT&amp;E Manufacture IOC</b>	<div style="border-top: 2px solid black; height: 10px; width: 60px;"></div>	▽					

## DEVELOPMENT SCHEDULE FOR EVA CAPABILITY PACKAGE NO. 2

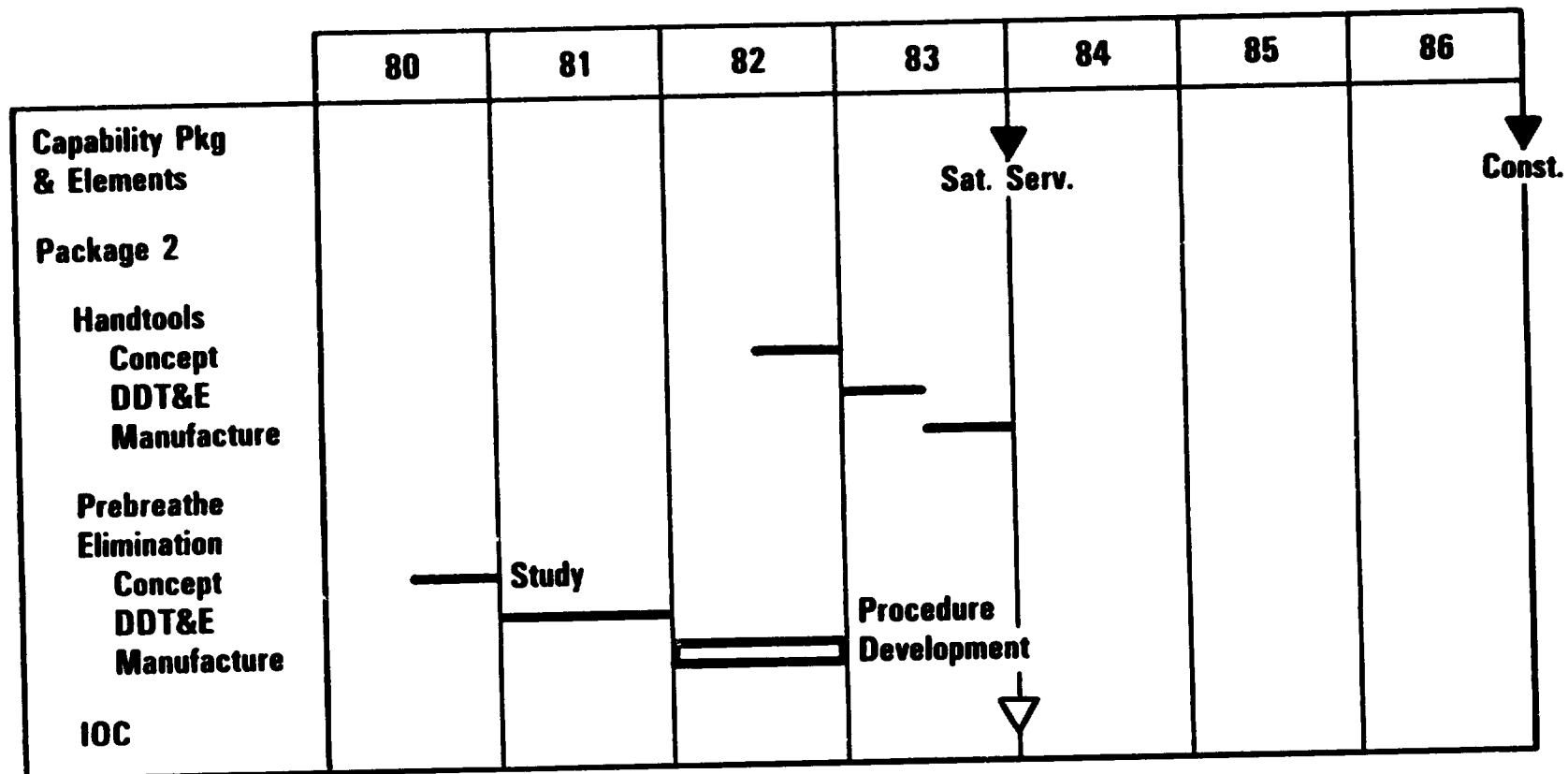


## DEVELOPMENT SCHEDULE FOR EVA CAPABILITY PACKAGE NO. 2 (Continued)

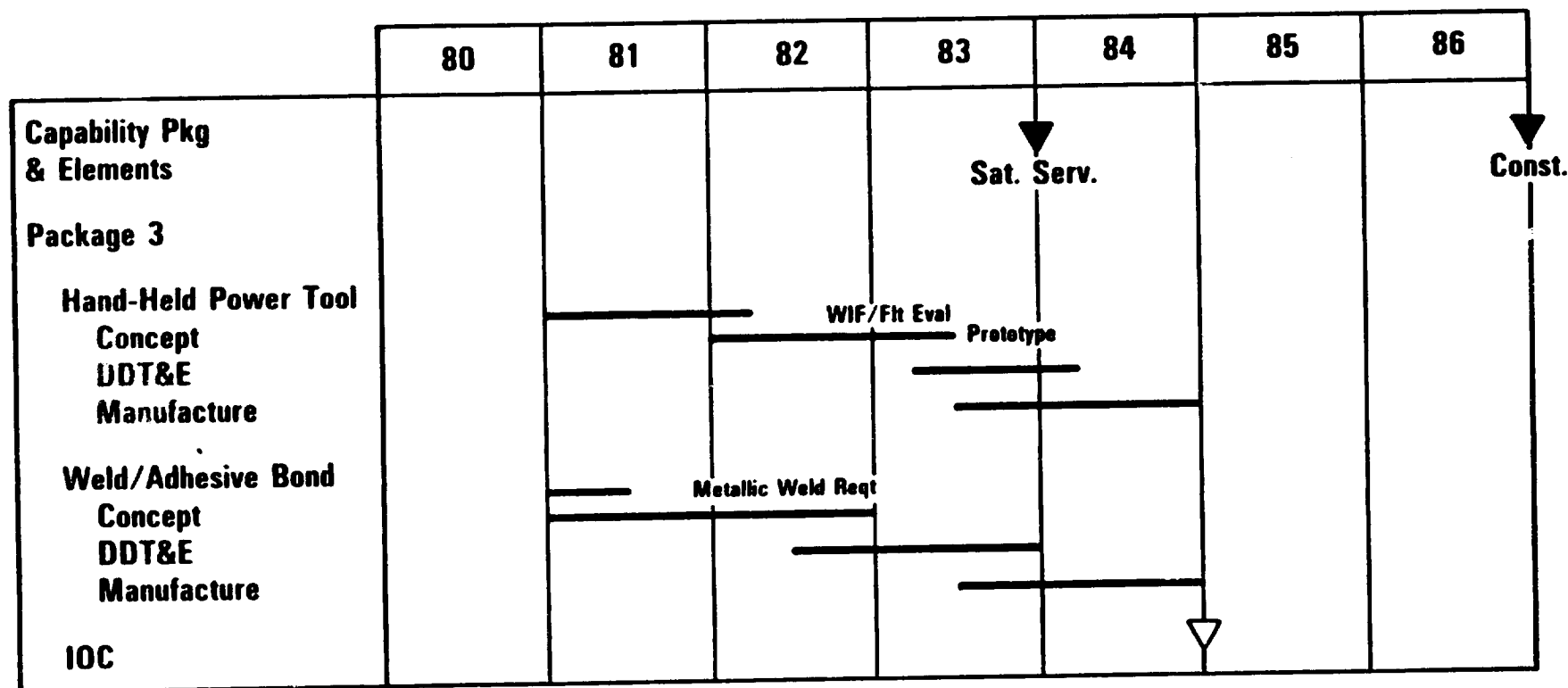




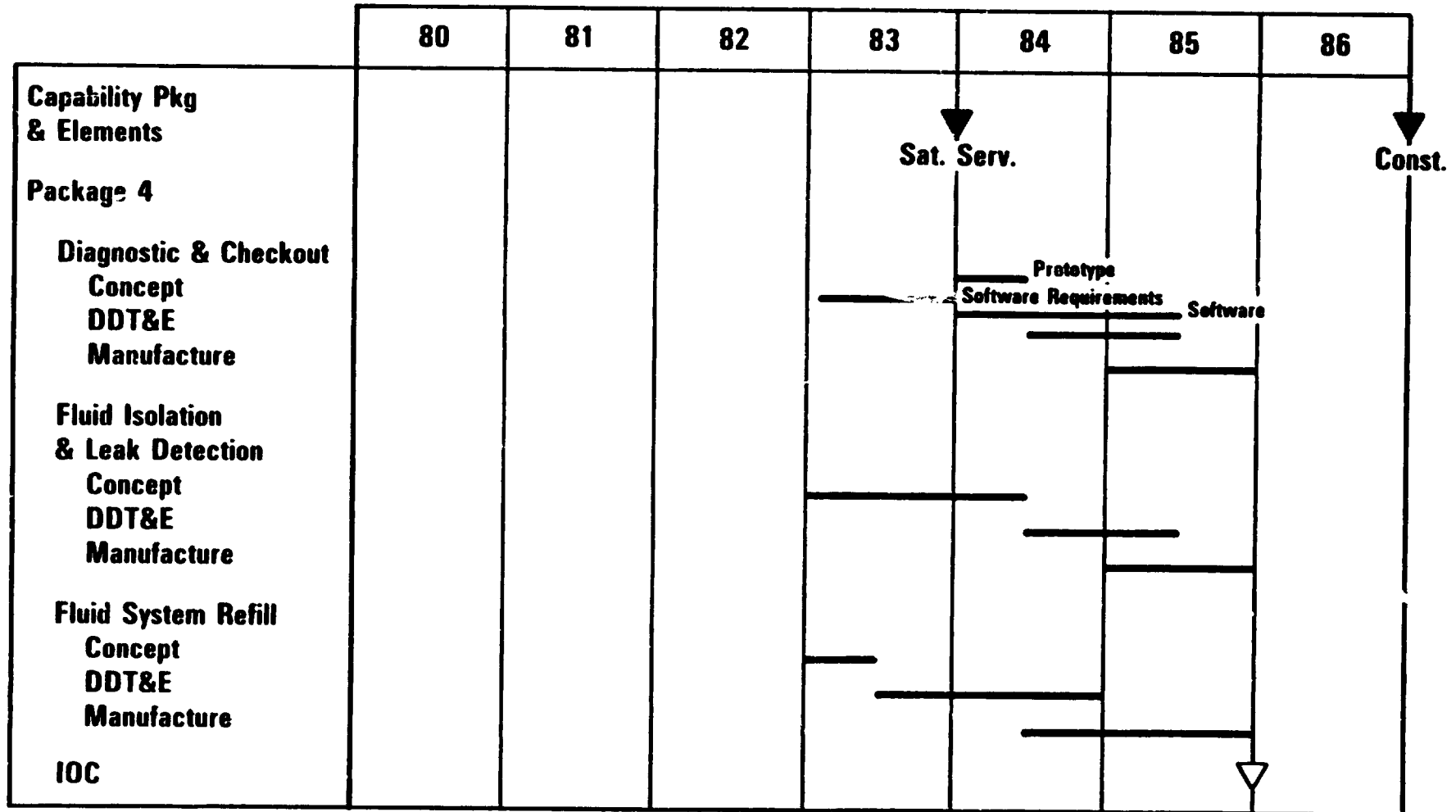
# DEVELOPMENT SCHEDULE FOR EVA CAPABILITY PACKAGE NO. 2 (Concluded)



## DEVELOPMENT SCHEDULE FOR EVA CAPABILITY PACKAGE NO. 3



# DEVELOPMENT SCHEDULE FOR EVA CAPABILITY PACKAGE NO. 4



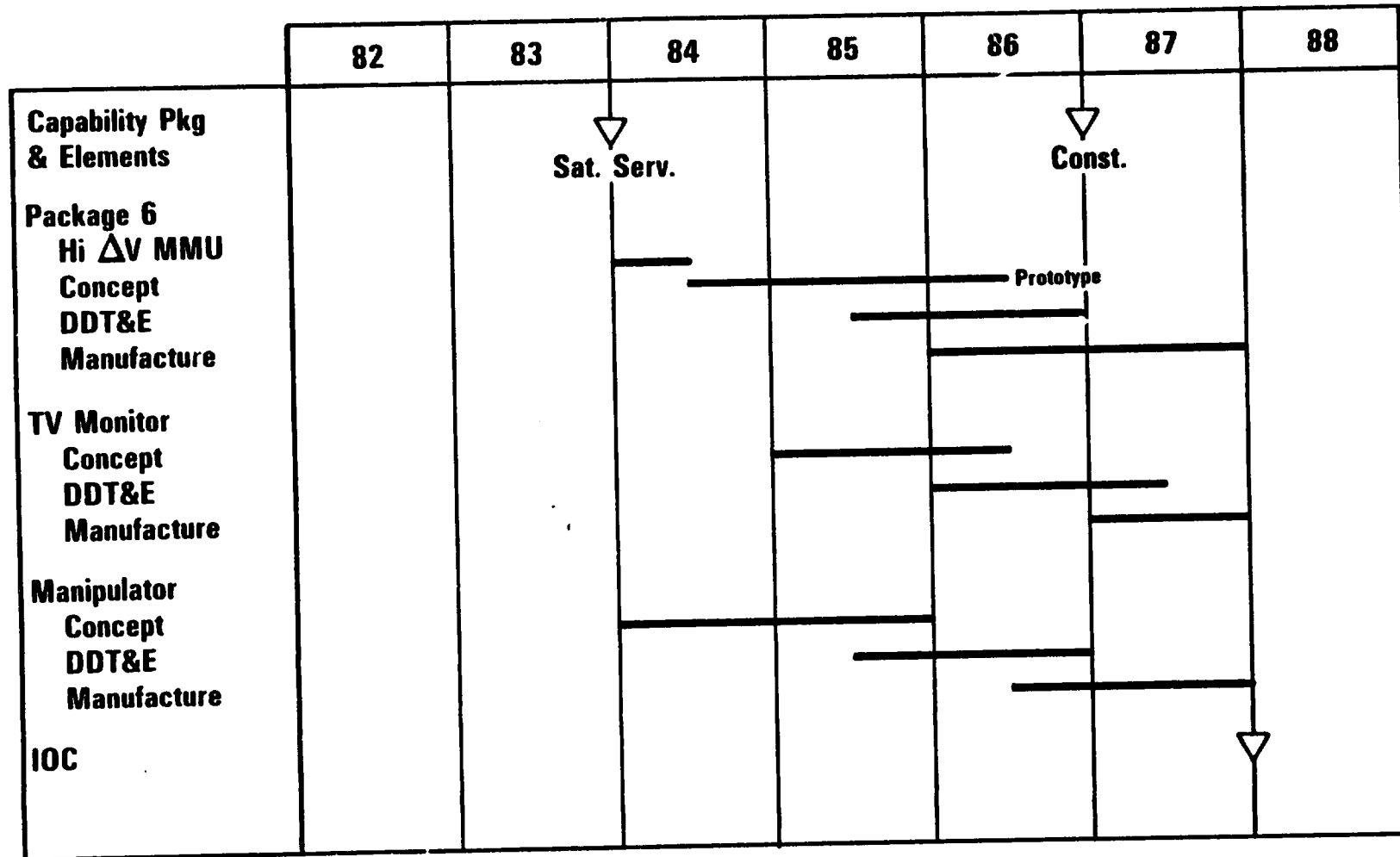
## DEVELOPMENT SCHEDULE FOR EVA CAPABILITY PACKAGE NO. 5

	80	81	82	83	84	85	86
<b>Capability Pkg &amp; Elements</b>				▼ Sat. Serv.			▼ Const.
<b>Package 5</b>							
<b>SSA Soft Goods</b>							
<b>Concept</b>					Joint Development		
<b>DDT&amp;E</b>						Prototype	
<b>Manufacture</b>							
<b>Hazards Protection</b>							
<b>Exposures &amp; Limits</b>							
<b>Concept</b>							
<b>DDT&amp;E</b>							
<b>Manufacture</b>							
<b>Enhanced Computer</b>							
<b>Concept</b>							
<b>DDT&amp;E</b>							
<b>Manufacture</b>							
<b>IOC</b>							▼

## DEVELOPMENT SCHEDULE FOR EVA CAPABILITY PACKAGE NO. 5 (Continued)

	80	81	82	83	84	85	86
<b>Capability Pkg &amp; Elements</b>				▼ Sat. Serv.			▼ Const.
<b>Package 5</b>							
<b>Regenerable CO<sub>2</sub></b>							
<b>Concept</b>						Prototype	
<b>DDT&amp;E</b>							
<b>Manufacture</b>							
<b>Non-Venting Heat Sink</b>							
<b>Concept</b>						Prototype	
<b>DDT&amp;E</b>							
<b>Manufacture</b>							
<b>Repackaged LSS</b>							
<b>DDT&amp;E</b>							
<b>Manufacture</b>							

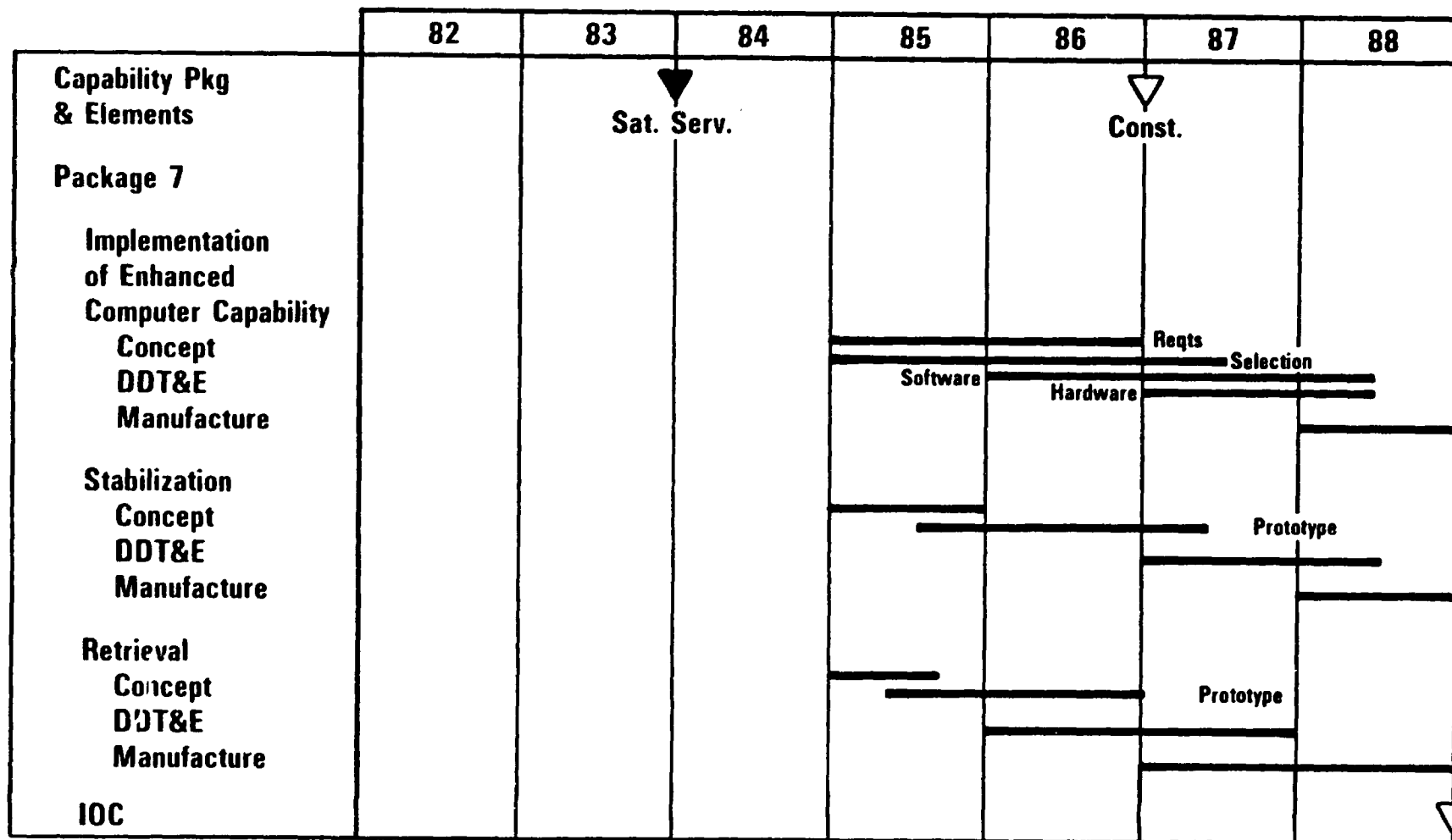
## DEVELOPMENT SCHEDULE FOR EVA CAPABILITY PACKAGE NO. 6



# **DEVELOPMENT SCHEDULE FOR EVA CAPABILITY PACKAGE NO. 6 (Continued)**

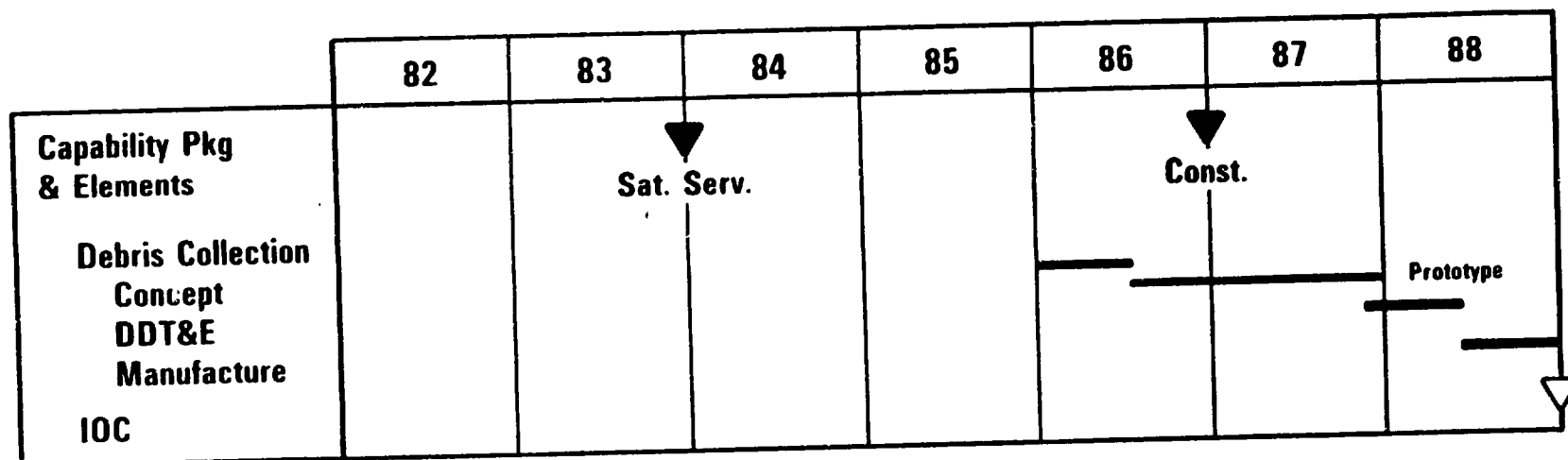
	82	83	84	85	86	87	88
<b>Capability Pkg &amp; Elements</b>		▽ Sat. Serv.			▽ Const.		
<b>Package 6</b>							
<b>Integrated Radiator &amp; Leg Enclosure</b>							
<b>Concept</b>							
<b>DDT&amp;E</b>							
<b>Manufacture</b>							
<b>Remote Service Kit</b>							
<b>DDT&amp;E</b>							
<b>Manufacture</b>							
<b>IOC</b>							▽

# DEVELOPMENT SCHEDULE FOR EVA CAPABILITY PACKAGE NO. 7





# **DEVELOPMENT SCHEDULE FOR EVA CAPABILITY PACKAGE NO. 7 (Continued)**



## SUMMARY OF EVA CAPABILITY DEVELOPMENT PROGRAM STARTS

The accompanying list summarizes the EVA capability packages and shows estimated program start dates to support projected IOC dates.

Each package is estimated to require three to four years to progress from program start through technology development to DDT&E and manufacture of flight hardware.

Planning for these programs must start in the near future if flight hardware is to be available to support the projected STS schedule. This is especially applicable to the near-in programs that require starts in 1981.

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# SUMMARY OF EVA CAPABILITY DEVELOPMENT PROGRAM STARTS

<u>PROGRAM</u>	<u>PACKAGE</u>	<u>CAPABILITY</u>	<u>CAPABILITY DEVELOPMENT REQUIRED</u>	<u>IOC</u>
<u>START</u>				
1981	2	Routine Servicing	Helmet, Gloves, Hand Tools Workstand, Adhesive Bond Tool, Refuel and Decontamination Facilities. Eliminate Prebreathe	1984
1981	3	Structural Repair	Hand-Held Power Tool Weld/Adhesive Bond	1985
1983	4	Mature Service Capability	Diagnosis and Checkout Fluid Isolation Fluid System Refill	1986
1982	5	Improved EMU Capability	Long Life Softgoods Hazards Protection Enhanced Computer Capability Regenerable CO <sub>2</sub> Removal Non-Venting Heat Sink Repackaged LSS	1987
1983	6	Near-in EVA Capability	Hi V MMU TV Monitor Manipulator Integrated Radiator/Leg Encasement, Remote Service Kit	1988
1984	7	More Distant EVA Capability	Implementation of Enhanced Computer Capability, Stabilization Kit Satellite Retrieval Kit Debris Collection	1989

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